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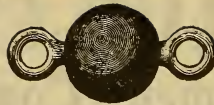
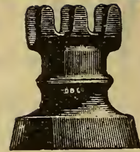
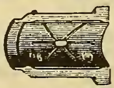
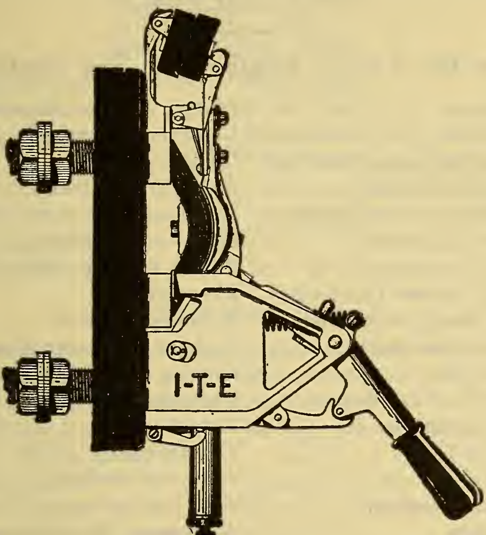




I-T-E Laminated Edgewise CIRCUIT BREAKER

ESPECIALLY DESIGNED FOR HEAVY STREET RAILWAY CIRCUITS



This type of instrument is now in use on a number of the most important Switchboards in this country and abroad.

An illustrated price list, showing front and side views of the Circuit Breaker, both open and closed, will be sent on application.

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Insulators
Insulator Racks
Instruments of all kinds
Lamps, Arc, Incandescent
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Oil Switches
Pedestal Switches
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Hauling Clamp for Wire
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Insulators

PRACTICAL ELECTRIC RAILWAY HAND BOOK

BY

ALBERT B. HERRICK

Consulting Electric Railway Engineer

NEW YORK:

STREET RAILWAY PUBLISHING COMPANY

120 Liberty Street

[1901]

PREFACE.

Every Street Railway Engineer requires data pertaining to his particular line of business, consisting of engineering facts, figures and dimensions. The author's present attempt is to collect together under one cover all such data as is directly applicable in the construction, testing or operation of electric railway systems, showing such appliances, structures and methods as have been adopted in practice by street railways in the United States. The author has made free use of all sources of technical information, especially the technical press and the works of leading writers, credit being given in every case.

No effort has been spared to make the work as free from errors as possible. The use of mathematics and formulas has been limited as far as possible so as to make the book useful to the great majority of practical workers, and to bring it down to as condensed a volume as possible. Many topics had to be reduced to their simplest terms, omitting data which would be of scientific interest to the expert.

The matter has been largely selected from data collected and compiled during the past twenty years by the author, which he has found useful in his engineering work, it being abridged and brought up-to-date.

It is the object of the author to make this handbook of value to engineers, operators and employees of street railways; and any corrections or new data and suggestions, which will assist him in improving and make further editions more valuable to co-laborers in this field, will be gratefully received.

ALBERT B. HERRICK.

AUGUST 1, 1901.

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MEASURES OF LENGTH.

	Inches in a	Feet in a	Yards in a	Rod, Pole or Perch in a	Furlong in a	Statute Mile in a	League in a	French Meters in a
1 Inch	1	.0833	.0277	.00505	....	....	....	.025399
I Foot	12	1	.333	.0606	.001515	....	....	.304801
1 Yard	36	3	1	.1818	.000568	....	....	.91440
1 Rod, Pole or Perch	198	16½	5½	1	.025	.003125	.001041	5.0292
1 Furlong	7,920	660	220	40	1	.125	.0467	201.16
1 Statute Mile	63,360	5,280	1,760	320	8	1	.333	1609.3
I League	......	15,840	5,280	960	24	3	1	....
1 French Meter	39.37	3.2808	1.0936	.1988	.004971	.0006214	....	....

1 Mil equals one thousandth of an inch. 1 Palm equals three inches. 1 Hand equals four inches. 1 Span equals nine inches. 1 Military Pace equals 2½ feet. 1 Fathom equals 6 feet. Geographical Mile fixed by U. S. at 6,080 feet, or 2,026 yards. 1 Degree of great circle of the earth, 69.77 statute miles.

SURVEYOR'S MEASURE.—MEASURE OF SURFACE.

	Inches in a	Links in a	Chains in a	Furlongs in a	Miles in a
Inch	1	.1262	.001262	.0001262	
Link	7.92	1	.01	.001	.000125
Chain (Gunther's)	792	100	1	.10	.0125
Furlong	7,920	1,000	10	1	.125
Mile	63,360	8,000	80	8	1

10 Square Chains equal 1 Acre. 1 Acre equals a square whose side is 208.71 feet long or 69.57 yards long. A strip 1 chain wide runs 8 acres per mile.

SQUARE MEASURE—MEASURES OF SURFACE.

	Sq. Inches in a	Sq. Feet in a	Sq. Yards in a	Sq. Rods P. or P. in a	Rods in a	Acres in a	Sq. Miles in a
1 Sq. Inch......	1	.006944	.000771	.0000255			
1 Sq. Foot......	144	1	.11111	.003673	.0000918		
1 Sq. Yard......	1,269	9	1	.033059	.000626	.0002066	
1 Sq. Rod, Pole or Perch.....	39,204	227.25	30.25	1	.025	.00625	.0000097
1 Rood....... .	1,568,160	10,890	1,210	40	1	.25	.00039
1 Acre..........	6,272,640	43,560	4,840	160	4	1	.0015535
1 Sq. Mile......		27,878,400	3,097,600	102,400	2,560	640	1

1 square inch equals 1.2732 circular inches. One circular inch is the area of a circle one inch in diameter having 0.7854 square inches. A circular mil is the area of a circle one thousandth of an inch in diameter. 1,000,000 circular mils equals one circular inch; 1 square inch equals 1,273,239 circular mils.

ENGLISH.		FRENCH.
10.764 square feet 1.196 square yards	=	1 square meter = 1 centiare,
1 square yard	=	.836 square meter.
1 square foot	=	.0929 square meter.
.155 square inches	=	1 square centimeter.
1 square inch	=	6.452 square centimeters.
.00155 square inches	=	1 square milimeter.
1 square inch	=	645.2 square milimeters.

1 are = 1 square decameter = 1076.41 square feet.

1 hectare = 100 ares = 107,641 square feet, 2.4711 acres.

1 square killometer = .386109 square miles, 247.11 acres.

SOLID OR CUBIC MEASURE.

Measure of Volume.

	Cubic Inches in a	Cubic Feet in a	Cubic Yards in a
Cubic Inch................	1	.000578	.0000214
Cubic Foot...............	1,728	1	.037037
Cubic Yard...............	49,656	57	1

1 Cord of Wood = a pile 4 x 4 x 8 feet = 128 cubic feet. 1 Perch of Masonry = 16½ x 1½ x 1 foot = 24¾ cubic feet. 1 U. S. standard bushel is a cylinder with a diameter of 18½ inches and 8 inches deep, containing 2150.42 cubic inches, 1.2445 cubic feet. This is known as a struck bushel. A heaped bushel contains 1¼ struck bushels. The capacity of a cylinder in U. S. bushels = square of diameter in inches multiplied by height in inches and multiplied by .0003652.

LIQUID MEASURE.

	Gills.	Pints.	Quarts.	Gallons.	Barrels.	Tierces.	Hogsheads.	Puncheons	Pipe or Butt
1 Gill....................	1	.25	.125	.03125	.000992	....	....	......	....
1 Pint....................	4	1	.50	.125	.003968	.002976	....	......	....
1 Quart....................	8	2	1	.25	.007936	.005952	.003968	.00297	.00198
1 Gallon....................	32	8	4	1	.03174	.0238	.01587	.0119	.007936
1 Barrel....................	1,008	252	126	31½	1	.75	.50	.375	.25
1 Tierce....................	.....	336	168	42	1⅓	1	.6666	.50	.333
1 Hogshead....................	.....	504	252	63	2	1½	1	.75	.50
1 Puncheon....................	.....	672	336	84	2⅔	2	1⅓	1	.6666
1 Pipe or Butt....................	.....	1,008	504	126	4	3	2	1½	1

The U. S. gallon contains 231 cubic inches; 7.4805 gallons = one cubic foot. A cylinder 7 ins. in diameter and 6 ins. high contains one gallon or 230.9 cubic inches. The British Imperial gallon contains 277.274 cubic inches or 1.20032 U. S. gallons.

The miners' inch varies in different parts of the country—from a delivery of 1.36 to 1.73 cubic feet per minute—due to the varying heads of water above the centre of the aperture. The most prevalent method is the flow of water through a slot 2 ins. high, and whatever length required cut in a plank 1¼ ins. thick. The lower edge of the slot should be 2 inches above the measuring box, and the plank extend 5 ins. high above the slot, making a 6 in. effective head. Each sq. inch of this slot delivers one miners' inch, and equal to about 1½ cubic feet of water per minute.

BOARD AND TIMBER MEASURE.

In measuring boards and timbers they are estimated in equivalent lumber 1 in. thick. To compute the number of feet board measure in a board or stick, multiply its length in feet by its breadth in feet by its thickness in inches.

To compute round timber when all its dimensions are given in feet, find the mean girth and diameter and multiply them together and divide this by four and multiply by the length of the timber which gives the result in cubic feet. On square timber, when all dimensions are given in inches, divide by 1728 to get cubic feet; when two dimensions are given in inches, divide by 144 to get cubic feet; when one dimension is given in inches, divide by 12 to get cubic feet.

CONTENTS IN FEET OF JOISTS, SCANTLING AND TIMBER.

LENGTH IN FEET.

Size.	12	14	16	18	20	22	24	26	28	30
	FEET, BOARD MEASURE.									
2 x 4	8	9	11	12	13	15	16	17	19	20
2 x 6	12	14	16	18	20	22	24	26	28	30
2 x 8	16	19	21	24	27	29	32	35	37	40
2 x 10	20	23	27	30	33	37	40	43	47	50
2 x 12	24	28	32	36	40	44	48	52	56	60
2 x 14	28	33	37	42	47	51	56	61	65	70
3 x 8	24	28	32	36	40	44	48	52	56	60
3 x 10	30	35	40	45	50	55	60	65	70	75
3 x 12	36	42	48	54	60	66	72	78	84	90
3 x 14	42	49	56	63	70	77	84	91	98	105
4 x 4	16	19	21	24	27	29	32	35	37	40
4 x 6	24	28	32	36	40	44	48	52	56	60
4 x 8	32	37	43	48	53	59	64	69	75	80
4 x 10	40	47	53	60	67	73	80	87	93	100
4 x 12	48	56	64	72	80	88	96	104	112	120
4 x 14	56	65	75	84	93	103	112	121	131	140
6 x 6	36	42	48	54	60	66	72	78	84	90
6 x 8	48	56	64	72	80	88	96	104	112	120
6 x 10	60	70	80	90	100	110	120	130	140	150
6 x 12	72	84	96	108	120	132	144	156	168	180
6 x 14	84	98	112	126	140	154	168	182	196	210
8 x 8	64	75	85	96	107	117	128	139	149	160
8 x 10	80	93	107	120	133	147	160	173	187	200
8 x 12	96	112	128	144	160	176	192	208	224	240
8 x 14	112	131	149	168	187	205	224	243	261	280
10 x 10	100	117	133	150	167	183	200	217	233	250
10 x 12	120	140	160	180	200	220	240	260	280	300
10 x 14	140	163	187	210	233	257	280	303	327	350
12 x 12	144	168	192	216	240	264	288	312	336	360
12 x 14	168	196	224	252	280	308	336	364	392	420
14 x 14	196	229	261	294	327	359	392	425	457	490

MEASURES OF WEIGHTS.

	Grains in a	Ounces in a	Pounds in a	Grammes in a	Kilogrammes in a
Grains............	1	.00228	.000143	.06479	.000064
Ounces, adv.......	437.5	1	.0625	28.349	.02835
Pounds, adv.......	7000.00	16	1	453.59	.45359
Grammes..........	15.432	.03527	.00205	1	.001
Kilogrammes.....	15432.36	35.274	2.2204	1000	1

1 carat is 3.168 grains or .205 grammes. 1 stone is 14 lbs. 1 quintal is 100 lbs. 1 quarter is 28 lbs. 1 hundred-weight is 112 lbs. There are twenty hundred-weight to one long ton or 2240 lbs. Net or short ton is 2000 lbs. Metric ton is 2204.6 lbs. In shipping, 100 cubic feet is equivalent to one registered ton.

MENSURATION.

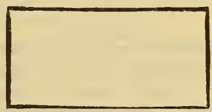
TABLE OF REGULAR POLYGONS.

No. of Sides.	Name of Polygon.	Area = Side x Side multiplied by	Radius of Circumscribed Circle = Side multiplied by	Radius of Inscribed Circle = Side multiplied by	Interior Angle Between Sides.	Angle at Center.
3	Triangle	.433013	.5773	.2887	60 degs.	120 degs
4	Square	1.000000	.7071	.5	90 degs.	90 degs.
5	Pentagon	1.720477	.8507	.6882	108 degs.	72 degs.
6	Hexagon	2.598076	1.0000	.866	120 degs.	60 degs.
7	Heptagon	3.633912	1.1524	1.0383	128$\frac{4}{7}$ degs.	51$\frac{3}{7}$ degs.
8	Octagon	4.828427	1.3066	1.2071	135 degs.	45 degs.
9	Nonagon	6.181824	1.4619	1.3737	140 degs.	40 degs.
10	Decagon	7.694209	1.6180	1.5388	144 degs.	36 degs.
11	Undecagon	9.365640	1.7747	1.7028	147$\frac{3}{11}$ degs.	32$\frac{8}{11}$ degs.
12	Dodecagon	11.196152	1.9319	1.866	150 degs.	30 degs.

LINES AND AREAS OF PLANE SURFACES.

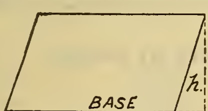
Square.—Area = side x side.
Side = area divided by side.
Diagonal = 1.4142 x side.


SQUARE.

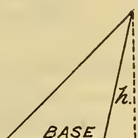

RECTANGLE.

Rectangle.—Area = side x base.
Base = area divided by side.
Side = area divided by base.
Diagonal = sq. root of $\overline{\text{(base x base) plus (side x side)}}$.

Parallelogram.—Area = height x base.
Height = area divided by base.
Base = area divided by height.



PARALLELOGRAM.



TRIANGLE.

Triangle.—Area = ½ base x height.
Base = 2 area divided by height.
Height = 2 area divided by base.

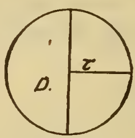
Angles 60 degs., 60 degs., 60 degs.—Area = .433 x base x base.
Base = 1.52 x sq. root of area.
Height = .866 x base.

Angles 30 degs., 60 degs., 90 degs.—Sides have the proportion of
$1:2:\sqrt{3}::1:2:1.732$.

Angles 30 degs., 30 degs., 120 degs.—Sides have the proportion of
$1:1:\sqrt{3}::1:1:1.732$.
Area = ¼ x long side x long side.

Angles 45 degs., 45 degs., 90 degs.—Sides have the proportion of
$1:1:\sqrt{2}::1:1:1.414$.

Angle 90 degs.—Hypothenuse = sq. root of (base x base) plus (side x side).
Side = sq. root of (hypoth. x hypoth.) minus (base x base).
Base = sq. root of (hypoth. x hypoth.) minus (side x side).



CIRCLE.

Circle.—Circumference = 3.14159 x diameter.
Area = 3.14159 x radius x radius.
= .7854 x diameter x diameter.
Diameter = circumference divided by 3.14159.
= sq. root of area x 1.12838.
3.14159 = approximately $\frac{22}{7}$
.7854 = approximately $\frac{11}{14}$
(See table for areas and circumferences of circles.)

Irregular Figure.—Area may be found by a planimeter, or the figure may be drawn on cross-section paper, and the number of squares and part squares included therein counted or estimated; the number of squares x the area of each square equals the total area.

SURFACES AND VOLUMES OF SOLIDS.

Cube.—Surface = 6 x one edge x one edge.
Volume = edge x edge x edge.

Parallelopiped.—Is a solid having six faces, all of which are parallelograms, and the pairs of which are parallel. Fig. 1.

Prisms.—The opposite ends are parallel, equal and similar., Fig. 2.

Cylinders.—The opposite ends are equal, parallel circles, Fig. 3.

Parallelopiped, Prism or Cylinder.—Total surface = area of two ends plus circumference of cross-section perpendicular to side x length of side.

Volume = area of one end (a) x perpendicular distance (h) between this end and the opposite end.

Volume = area of cross-section perpendicular to the sides x length of side (1).

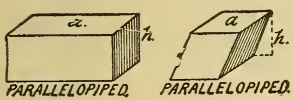


FIG. 1.

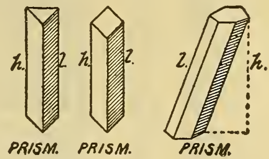


FIG. 2

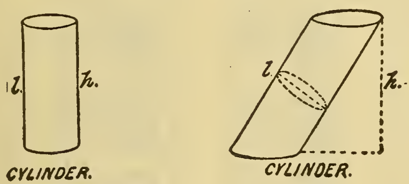


FIG. 3.

Sphere.—Area of surface = 3.14159 x diameter x diameter.
= 6 x volume divided by diameter.

Volume = 4.1888 x radius x radius x radius.
= .5236 x diameter x diameter x diameter.

AREAS AND CIRCUMFERENCES OF CIRCLES.

Diameter, Inches.	Circumference, Inches	Circumference, Feet.	Area, Sq. inches	Area, Feet.	Diameter. Feet.	Diameter. Inches.
1-64	.049087		.00019			
1-32	.098175		.00077			
3-64	.147262		.00173			
1-16	.196350		.00307			
3-32	.294524		.00690			
1-8	.392699		.01227		....	1½
5-32	.490874		.01917			
3-16	.589049		.02761			

AREAS AND CIRCUMFERENCES OF CIRCLES.—Continued.

Diameter, Inches.	Circumference, Inches. feet.	Area, Sq. inches Feet.	Diameter, Feet.	Diameter, Inches.
7-32	.687223	.03758		
1-4	.785398	.04909	....	3
9-32	.883573	.06213		
5-16	.981748	.07670		
11-32	1.07992	.09281		
3-8	1.17810	.11045	....	4½
13-32	1.27627	.12962		
7-16	1.37445	.15033		
15-32	1.47262	.17257		
1-2	1.57080	.19635	....	6
17-32	1.66897	.22166		
9-16	1.76715	.24850		
19-32	1.86532	.27688		
5-8	1.96350	.30680	....	7½
21-32	2.06167	.33824		
11-16	2.15984	.37122		
23-32	2.25802	.40574		
3-4	2.35619	.44179	....	9
25-32	2.45437	.47937		
13-16	2.55254	.51849		
27-32	2.65072	.55914		
7-8	2.74889	.60132	....	10½
29-32	2.84707	.64504		
15-16	2.94524	.69029		
31-32	3.04342	.73708		
1.	3.14159	.78540	1	
1-16	3.33794	.88664		
1-8	3.53429	.99402	1	1½
3-16	3.73064	1.1075		
1-4	3.92699	1.2272	1	3
5-16	4.12334	1.3530		
3-8	4.31969	1.4849	1	4½
7-16	4.51604	1.6230		
1-2	4.71239	1.7671	1	6
9-16	4.90874	1.9175		
5-8	5.10509	2.0739	1	7½
11-16	5.30144	2.2365		
3-4	5.49779	2.4053	1	9
13-16	5.69414	2.5802		
7-8	5.89049	2.7612	1	10½
15-16	6.08684	2.9483		
2.	6.28319	3.1416	2	
1-16	6.47953	3.3410		
1-8	6.67588	3.5466	2	1½
3-16	6.87223	3.7583		
1-4	7.05858	3.9761	2	3

AREAS AND CIRCUMFERENCES OF CIRCLES.—Continued.

Diameter, Inches.	Circumference, Inches Feet.	Area, Sq. inches Feet.	Diameter. Feet.	Diameter. Inches.
5-16	7.26493	4.2000		
3-8	7.46128	4.4301	2	4½
7-16	7.65763	4.6664		
1-2	7.85398	4.9087	2	6
9-16	8.05033	5.1572		
5-8	8.24668	5.4119	2	7½
11-16	8.44303	5.6727		
3-4	8.63938	5.9396	2	9
13-16	8.83573	6.2126		
7-8	9.03208	6.4918	2	10½
15-16	9.22843	6.7771		
3.	9.42478	7.0686	3	
1-16	9.62113	7.3662		
1-8	9.81748	7.6699	3	1½
3-16	10.0138	7.9798		
1-4	10.2102	8.2958	3	3
5-16	10.4065	8.6179		
3-8	10.6029	8.9462	3	4½
7-16	10.7992	9.2806		
1-2	10.9956	9.6211	3	6
9-16	11.1919	9.9678		
5-8	11.3883	10.321	3	7½
11-16	11.5846	10.680		
3-4	11.7810	10.045	3	9
13-16	11.9773	11.416		
7-8	12.1737	11.793	3	10½
15-16	12.3700	12.177		
4.	12.5664	12.566	4	
1-16	12.7627	12.962		
1-8	12.9591	13.364	4	1½
3-16	13.1554	13.772		
1-4	13.3518	14.186	4	3
5-16	13.5481	14.607		
3-8	13.7445	15.033	4	4½
7-16	13.9408	15.466		
1-2	14.1372	15.904	4	6
9-16	14.3335	16.349		
5-8	14.5299	16.800	4	7½
11-16	14.7262	17.257		
3-4	14.9226	17.721	4	9
13-16	15 1189	18.190		
7-8	15.3153	18.665	4	10½
15-16	15.5116	19.147		
5.	15.7080	19.635	5	
1-16	15.9043	20.129		
1-8	16.1007	20.629	5	1½

AREAS AND CIRCUMFERENCES OF CIRCLES.—Continued.

Diameter, Inches.	Circumference, Inches. Feet.	Area, Sq. inches. Feet.	Diameter. Feet.	Diameter. Inches.
3-16	16.2970	21.135		
1-4	16.4934	21.648	5	3
5-16	16.6897	22.166		
3-8	16.8861	22.691	5	4½
7-16	17.0824	23.221		
1-2	17.2788	23.758	5	6
9-16	17.4751	24.301		
5-8	17.6715	24.850	5	7½
11-16	17.8678	25.406		
3-4	18.0642	25.967	5	9
13-16	18.2605	26.535		
7-8	18.4569	27.109	5	10½
15-16	18.6532	27.688		
6.	18.8496	28.274	6	
1-8	19.2423	29.465	6	1½
1-4	19.6350	30.680	6	3
3-8	20.0277	31.919	6	4½
1-2	20.4204	33.183	6	6
5-8	20.8131	34.472	6	7½
3-4	21.2058	35.785	6	9
7-8	21.5984	37.122	6	10½
7.	21.9919	38.485	7	
1-8	22.3838	39.871	7	1½
1-4	22.7765	41.282	7	3
3-8	23.1692	42.718	7	4½
1-2	23.5619	44.179	7	6
5-8	23.9546	45.664	7	7½
3-4	24.3473	47.173	7	9
7-8	24.7400	48.707	7	10½
8.	25.1327	50.265	8	
1-8	25.5254	51.849	8	1½
1-4	25.9181	53.456	8	3
3-8	26.3108	55.088	8	4½
1-2	26.7035	56.745	8	6
5-8	27.0962	58.426	8	7½
3 4	27.4889	60.132	8	9
7-8	27.8816	61.862	8	10½
9.	28.2743	63.617	9	
1-8	28.6670	65.397	9	1½
1-4	29.0597	67.201	9	3
3-8	29.4524	69.029	9	4½
1-2	29.8451	70.882	9	6
5-8	30.2378	72.760	9	7½
3-4	30.6305	74.662	9	9
7-8	31.0232	76.589	9	10½

AREAS AND CIRCUMFERENCES OF CIRCLES.—Continued.

Diameter, Inches.		Circumference, Inches.	Feet.	Area, Sq. inches.	Feet.	Diameter. Feet.	Inches.
10.		31.4159		78.540		10	
	1-8	31.8086		80.516		10	1½
	1-4	32.2013		82.516		10	3
	3-8	32.5940		84.541		10	4½
	1-2	32.9867		86.590		10	6
	5-8	33.3794		88.664		10	7½
	3-4	33.7721		90.763		10	9
	7-8	34.1648		92.886		10	10½
11.		34.5575		95.033		11	
	1-8	34.9502		97.205		11	1½
	1-4	35.3429		99.402		11	3
	3-8	35.7356		101.62		11	4½
	1-2	36.1283		103.87		11	6
	5-8	36.5210		106.14		11	7½
	3-4	36.9137		108·43		11	9
	7-8	37.3064		110.75		11	
12.		37.6991		113.10		12	10½

EARTHS, ORES, STONES AND MISCELLANEOUS.

MATERIAL.	Weight, lbs. per cubic ft.
Asbestos, starry	192
Asphalte	150
Asphaltum	87
Belts, leather, per sq. ft., per ply thickness	(13–16)
Bitumen, red	72
Bitumen, brown	52
Borax	107
Brick, best pressed	150
Brick, common	112
Brick, fire	140–150
Brick, hard	125
Brick, soft, inferior	100
Brickwork, ordinary	112
Brickwork, pressed brick	140
Brickwork, coarse, inferior soft bricks	100
Carbon	219
Cement, hydraulic, ground loose, Rosendale	50–56
Cement, hydraulic, ground loose, Louisville	50
Cement, hydraulic, ground loose, Copley	54
Cement, hydraulic, ground loose, Portland	95–102
Chalk	95
Chalk	174
Clay	120
Clay, with gravel	155
Coal, anthracite, Pennsylvania	93
Coal, anthracite, broken to any size, loose	52-56
Coal, anthracite, broken, moderately shaken	56-60
Coal, anthracite, broken, 40-43 cu. ft. per ton.	

EARTH, ORES, STONES, ETC.—Continued.

Material.	Weight lbs. per cubic ft.
Coal, bituminous	84
Coal, bituminous, broken to any size, loose	47–52
Coal, bituminous, broken, moderately shaken	51–56
Coal, bituminous, broken, 43–48 cu. ft. per ton.	
Coke, loose, of good coal	63
Concrete, dry, 130–160, average	150
Earth, common loam, dry, loose	72–80
Earth, common loam, dry, shaken	82–92
Earth, common loam, dry, moderately rammed	90–100
Earth, common loam, slightly moist, loose	70–76
Earth, common loam, quite moist, loose	66–68
Earth, common loam, quite moist, shaken	75–90
Earth, common loam, quite moist, moderately packed	90–100
Earth, mud dry, close	80–110
Earth, mud wet, fluid	104–120
Emery	250
Flint	162
Glass, window or flooring	157
Granite	160–180
Graphite	137
Gravel	109
Grindstone	134
Gutta-percha	61.1
Ice at 32 degrees Fahrenheit	57.5
Leather	60.
Leather belts, per sq. ft., per ply thickness	(13–16)
Lime, quick, ground loose or in small lumps	53.
Lime, quick, ground well shaken	64.
Lime, quick, ground thoroughly shaken	75.
Lime, hydraulic	171
Limestone	168
Magnesia carbonate	150
Magnesium	109
Marble, Dorset, Vermont	165
Marble, East Chester, New York	180
Marble, North Bay, Wisconsin	175
Marble, Italian, common	168
Marble, Mill Creek, Illinois, drab	172
Masonry, of granite or limestone, well dressed	165
Masonry, of sandstone, well dressed	144
Masonry, of mortar rubble, well scabbled	154
Masonry, of mortar rubble, dry, well scabbled	138
Mica	171–193
Millstone	155
Mortar, hardened	87–118
Mud (see Earth).	
Paving stone	151
Pitch	72
Plaster of Paris	141
Plaster of Paris, ground loose	56
Plaster of Paris, ground well shaken	64
Plumbago	131
Porcelain	140
Quartz	165
Quartz, finely pulverized	90–112

EARTH, ORES, STONES, ETC.—Continued.

Material.	Weight lbs. per cubic ft.
Rosin	69
Rotten stone	124
Rubber	58
Salt, coarse	42–70
Salt, fine table	49
Sand, perfectly dried, loose, usually	90–106
Sand, naturally moist, loose, usually	85 90
Sand, perfectly wet	118–120
Sandstone, building	151
Sandstone, quarried and piled	86
Sewer pipe	141
Slate	168–181
Slate, purple	174
Snow, fresh fallen	5-12
Snow, compacted by rain	15–50
Sulphur	125
Tallow	58.6
Tar, coal	62
Terra-cotta, solid	122
Terra-cotta, hollow, 1½ ins. thick, including air spaces	65–80
Terra-cotta, hollow, 12 x 18 ins. or larger on face	70
Trap rock	187
Trap rock, broken, in piles	107
Turf or peat, dry, unpressed	20–30
Wax, bees	60.5

Tensile Strength.	Lbs. per sq. in.	Tons per. (2000 lbs.) sq. ft.
Brick, 40 to 400	220	15.8
Cement, hydraulic, Portland, pure, 7 days in water	300	21.6
Cement, 6 months old	450	32.4
Cement, 1 year old	550	39.6
Common hydraulic cements average 1-6 as much. The last, neat, adhere to brick and stone with from 15 to 50 lbs. when only 1 month old	32	2.3
At end of 1 year 3 times as much	96	6.9
Concrete	180	13
Glass, 2,500 to 9,000	5,750	414
Glue holds wood together with from 300 to 800	550	39.6
Granite	1,000	72
Gutta-percha	3,500	252
Leather belts, 1,500 to 5000. Good	3,000	216
Marble, strong, white, Italy	1,034	74.5
Marble, Champlain, variegated	1,666	120
Marble, Glenn's Falls, N. Y., blk., 750 to 1034	892	64.3
Marble, Montgomery Co., Pa., gray	1,175	84.7
Marble, Montgomery Co., Pa., white	734	53
Marble, Lee, Massachusetts, white	875	63
Marble, Manchester, Vermont, 550 to 800	675	48.6
Marble, Tennessee, variegated	1,034	74.5
Mortar, common, 6 months old, 10 to 20	15	1.08
Plaster of Paris, well set	70	5

EARTH, ORES, STONES, ETC.—Continued.

Tensile Strength.

MATERIAL.	Lbs. per sq. in.	Tons per (2000 lbs.) sq. ft.
Rope, Manilla, best	12,000	864
Rope, hemp, best	15,000	1080
Sandstone, Ohio	105	7.56
Sandstone, Pictou, N. S	434	31.2
Sandstone, Connecticut, red	590	42.5
Slate, Lehigh	2,475	178
Slate, Peach bottom, 3,025 to 4,600	3,812	275
Stone, Ransome's artificial	300	21.6

Compressive Strength.

	Lbs. per sq. in.	Tons (2000 lbs.) per sq. ft.
Brick	550–4,100	40–300
Brickwork, ordinary, cracks with	280–420	20–30
Brickwork, good in cement	420–550	30–40
Brickwork, first rate in cement	700–970	50–70
Cement, 7 days in water, Portland, neat	1,050–2,100	75–150
Cement, 7 days in water, U. S. common, neat	210–420	15–30
Concrete. Portland, sand and gravel or broken stone	165–260	12–18
Concrete, Portland, 6 months old	670–1,000	48–72
Concrete, Portland, 12 months old	1,000–1,670	74–120
Concrete, with common hydraulic cements about ½ to ¼ as much.		
Flagging, North River, N. Y	13,400	960
Glass, green crown and flint	18,000–32,000	1,300–2,300
Granite, U. S	13,000–28,000	940–2,000
Ice, pure, hard	290–900	21–64
Ice, inferior	220–820	16–59
Limestone, U. S	6,000–23,000	430–1,660
Marble, Lee, Massachusetts	23,000	1,660
Marble, Rutland, Vermont	10,700	770
Marble, Montgomery Co., Pa	10,000	720
Marble, Colton, California	17,800	1,280
Marble, Italian	12,100	870
Mortar, 1 of lime, 3 of sand, 14½ months	118–135	8.8–9.7
Plaster of Paris, 1 day	550	40
Plaster of Paris, 4 months	1,980	142
Rubble masonry, good coursed is $\frac{4}{10}$ of that of the stone of which it is built. The strength of common rubble is not much greater than its mortar.		
Sandstone, American	6,000–12,000	430–860
Sandstone, New York	10,000–42,000	720–3,000
Slate	5,500–11,000	400–800
Terra-cotta, solid	5,200–7,000	375–500

METALS.

Material.	Weight, Cubic Inches.	Lbs. per Cubic Foot.	Ultimate Strength, Lbs. per Sq. In.	
			Tensile.	Compressive.
Aluminum, bar	.0937	162	28,000	....
Aluminum, cast	.0932	161	15 000	12,000
Aluminum, rolled	.0972	168	24,000	....
Antimony, cast	.0938	162	1,000	....
Bismuth, cast	.351	607	3,200	....
Copper, bolts	.321	555	36,000	100,000
Copper, cast	.314	542	20,000	117,000
Copper, electrolytic	.322	556	....	....
Copper, rolled plates	.318	550	30,000	100,000
Gold, cast, pure	.697	1,204	20,000	....
Gold hammered	.704	1,217	....	....
Iron, cast	.260	450	20,000	100,000
Iron, malleable	.260	450	48,200	....
Iron, structural	.278	480	42,000	....
Iron, wrought	.278	480	50,000	50,000
Lead, cast	.411	711	2,050	7,350
Lead, pipe	.414	716	1,650	....
Lead, red	.324	560	....	....
Lead, rolled	.412	712	2,500	....
Mercury	.491	849	....	....
Nickel	.318	542	....	....
Nickel, cast	.299	517	....	....
Platinum, hammered	.736	1,271	....	....
Platinum, rolled	.798	1,379	55,000	....
Silver, cast, pure	.379	654	40,000	....
Silver, hammered	.380	657	....	....
Steel, cast, from	.284	490	70,000	105,000
Steel, cast, to	.284	490	70,000	250 000
Steel, plate	.284	490	60,000	120,000
Steel, rails	.284	490	70,000	100,000
Steel, rivet	.284	490	54,000	....
Steel, shaft	.284	490	85,000	....
Steel, structural	.284	490	65,000	....
Tin	.266	459	4,600	15,500
Zinc, cast	.248	429	3,350	....
Zinc, rolled	.260	449	7,500	....

ALLOYS.

Material.	Weight, Cubic Inches.	Lbs. per Cubic Foot.	Ultimate Strength, Lbs. per Sq. In.	
			Tensile.	Compressive.
Aluminum Bronze, 1¼ per cent. Al	.313	541	25,000	....
Aluminum Bronze, 11 per cent. Al	.261	451	100,000	130,000
Babbitt Metals	.264	456	....	....
Brass, sheet	.297	514	31,000	....
Brass, cast, from	.293	506	18,000	50,000
Brass, cast, to	.293	506	18,000	160,000
Bronze, gun metal, from	.307	530	36.000	....
Bronze, gun metal, to	.316	546	36,000	....
Bronze, ordinary, from	.297	514	23,500	....
Bronze, ordinary, to	.314	543	23,500	....
Bronze, phosphor, from	.333	576	22,000	....
Bronze, phosphor, to	.333	576	74,000	....
German Silver, from	.252	436	81.700	....
German Silver, to	.252	436	92,200	....

WIRES.

Material.	Pounds per		Tensile Strength. Lbs. per circ. mil.
	Million cir. Mil. Ft.	Cubic Foot.	
Aluminum, from	.919	167	.0236
Aluminum, to	.919	167	.0511
Bi-Metallic (Copper Steel)	2.87	526	.0511
Brass, annealed	2.86	524	.0385
Brass, hard	2.86	524	.063
Bronze, phosphor, annealed	3.14	576	.0495
Bronze, phosphor, hard	3.14	576	.118
Bronze, silicon, from	3.04	558	.044
Bronze, silicon, to	3.04	558	.118
Copper, soft, from	3.027	555	.025
Copper, soft, to	3.027	555	.030
Copper, hard, from	3.027	555	.0354
Copper, hard, to	3.027	555	.0534
German Silver, from	2.38	436	.0642
German Silver, to	2.38	436	.0725
Gold, from	6.60	1,210	.0195
Gold, to	6.60	1,210	.0236
Iron, bright	2.65	486	.063
Iron, gal. line wire "B. B."	2.63	482	.046
Iron, gal. line wire "E. B. B."	2.63	482	.0416
Piano Wire, from	....	....	.236
Piano Wire, to	....	....	.267
Platinum, annealed	7.3	1,338	.0416
Steel, bright	2.67	490	.081
Steel, gal. line wire	2.65	486	.0515
Silver, annealed	3.46	634	.0314

WOOD.

Common Name.	Weight per Cu. Ft.		Lbs. Mean.	Strength Lbs. per sq. in.	
	From	To		Tensile.	Compres-sive.
Apple	45	49	47	12,700	....
Ash, Amer. White	37	52	45	11,000	4,400
Bamboo	19	25	22	6,000	....
Birch	35	46	41	10,000	5,300
Cedar, Amer.	31	47	39	7,000	4,000
Cherry	38	45	41	....	....
Chestnut	29	41	35	8 700	3,600
Cypress	26	41	33	4,000	4,000
Elm	34	49	41	4,000	4,500
Fir	30	44	37	6,700	3,500
Hemlock	22	26	24	5,800	3,500
Hickory, Amer.	43	59	51	7,300	5,300
Iron Wood, Black	....	....	81	....	......
Lignum Vitae, Amer.	40	83	62	7,300	6,700
Mahogany	35	66	51	5.300	6,000
Maple	35	49	42	6,700	5,300
Maple, Bird's Eye	....	....	36	....	......
Oak, Live	60	78	69	6,700	5,000
Oak, White	43	54	48	6,700	4,700
Oak, Red	45	47	46	6,700	4,700
Pine, White	22	34	28	6.700	3,600
Pine, Yellow, Northern	30	39	35	10,000	....
Pine, Yellow, Southern, Long Leaf	41	51	46	12,600	5,700
Spruce	25	31	28	6,700	3,000
Tamarack	....	....	24	....	....
Teak	41	61	51	10,000	8,000
Walnut, Black	31	42	36	5,300	5,300
White Wood	....	....	26	....	......
Willow	31	37	34	8,700	3,000

LIQUIDS.

Material.	Weight.		Pounds per		
	Cubic Inch.	Cubic Foot.	U. S. Gallon.	U. S. Barrel. (43.21 gal.)	U. S. Hogshead (63 gals.)
Acid, muriatic......	.0433	74.8	10.00	432	630
Acid, nitric.........	.0439	75.8	10.13	438	638
Acid, sulphuric.....	.0667	115.2	15.40	665	970
Alcohol, pure.......	.0285	49.5	6.62	286	417
Alcohol, 95%	.0293	50.9	6.80	294	429
Alcohol, 50%	.0335	58.2	7.78	336	490
Ammonia, 27.9%.....	.0319	55.5	7.42	321	467
Carbon, disulphide..	.0453	78.6	[illegible].51	454	662
Ether, sulphuric....	.0258	44.8	5.99	259	377
Oil, linseed	.0337	58.6	7.87	338	494
Oil, olive	.0330	57.3	7.66	331	483
Oil, palm	.0348	60.4	8.07	349	509
Oil, petroleum......	.0280	48.6	6.50	281	409
Oil, petroleum......	.0316	54.8	7.33	317	462
Oil, rape............	.0330	57.3	7.66	331	483
Oil, turpentine......	.0312	54.2	7.25	313	457
Oil, whale	.0330	57.3	7.66	331	483
Tar.................	.0359	62.3	8.33	360	525
Water, standard...	.0359	62.35	8.335	360.2	525.1
Water, fresh........	.0360	62.5	8.35	361	526
Water, sea..........	.0368	64	8.56	370	539

GASES.

PROPERTIES OF SATURATED STEAM.

Vacuum Gauge, In. of Mercury.	Absolute Pressure lbs. per sq. in.	Temperature Fahr.	Total Heat above 32° F.		Latent Heat L. = H-h Heat Units.	Relative Volume. Vol. of Water at 39° F. = 1.	Volume. Cu. Ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam, lb.
			In the Water h Heat Units.	In the Steam H Heat Units.				
29.74	.089	32.	0.	1091.7	1091.7	208080.	3333.3	.00030
29.67	.122	40.	8.	1094.1	1086.1	154330.	2472.2	.00040
29.56	.176	50.	18.	1097.2	1079.2	107630.	1724.1	.00058
29.40	.254	60.	28.01	1100.2	1072.2	76370.	1223.4	.00082
29.19	.359	70.	38.02	1103.3	1065.3	54660.	875.61	.00115
28.90	.502	80.	48.04	1106.3	1058.3	39690.	635.80	.00158
28.51	.692	90.	58.06	1109.4	1051.3	29290.	469.20	.00213
28.00	.943	100.	68.08	1112.4	1044.4	21830.	349.70	.00286
27.88	1.	102.1	70.09	1113.1	1043.0	20623.	334.23	.00299
25.85	2.	126.3	94.44	1120.5	1026.0	10730.	173.23	.00577
23.83	3.	141.6	109.9	1125.1	10 5.3	7325.	117.98	.00848
21.78	4.	153.1	121.4	1128.6	1007.2	5588.	89.80	.01112
19.74	5.	162.3	130.7	1131.4	1000.7	4530.	72.50	.01373
17.70	6.	170.1	138.6	1133.8	995.2	3816.	61.10	.01631
15.67	7.	176.9	145.4	1135.9	990.5	3302.	53.00	.01887
13.63	8.	182.9	151.5	1137.7	986.2	2912.	46.60	.02140
11.60	9.	188.3	156.9	1139.4	982.4	2607.	41.82	.02391
9.56	10.	193.2	161.9	1140.9	979.0	2361.	37.80	.02641
7.52	11.	197.8	166.5	1142.3	975.8	2159.	34.61	.02889
5.49	12.	202.0	170.7	1143.5	972.8	1990.	31.90	.03136
3.45	13.	205.9	174.7	1144.7	970.0	1846.	29.58	.03381
1.41	14.	209.6	178.4	1145.9	967.4	1721.	27.59	.03625
Gauge Pressure lbs. per sq. in.	14.7	212.	180.9	1146.6	965.7	1646.	26.36	.03794
0.304	15.	213.0	181.9	1146.9	965.0	1614.	25.87	.03868
1.3	16.	216.3	185.3	1147.9	962.7	1519.	24.33	.04110
2.3	17.	219.4	188.4	1148.9	960.5	1434.	22.98	.04352
3.3	18.	222.4	191.4	1149.8	958.3	1359.	21.78	.04592
4.3	19.	225.2	194.3	1150.6	956.3	1292.	20.70	.04831
5.3	20.	227.9	197.0	1151.5	954.4	1231.	19.72	.05070
6.3	21.	230.5	199.7	1152.2	952.6	1176.	18.84	.05308
7.3	22.	233.0	202.2	1153.0	950.8	1126.	18.03	.05545
8.3	23.	235.4	204.7	.7	949.1	1080.	17.30	.05782
9.3	24.	237.8	207.0	1154.5	947.4	1038.	16.62	.06018
10.3	25.	240.0	209.3	1155.1	945.8	998.4	15.99	.06253
11.3	26.	242.2	211.5	.8	944.3	962.3	15.42	.06487
12.3	27.	244.3	213.7	1156.4	942.8	928.8	14.88	.06721
13.3	28.	246.3	215.7	1157.1	941.3	897.6	14.38	.06955
14.3	29.	248.3	217.8	.7	939.9	868.5	13.91	.07188

PROPERTIES OF SATURATED STEAM.—Continued.

Gauge Pressure, lbs. per sq. in.	Absolute Pressure, lbs. per sq. in.	Temperature Fahr.	Total heat above 32° F.		Latent Heat L.= H-h Heat Units.	Relative Volume. Vol. of Water at 39° F.=1.	Volume. Cu. Ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam, lb.
			In the Water h Heat Units.	In the Steam H Heat Units.				
15.3	30.	250.2	219.7	1158.3	938.9	841.3	13.48	.07420
16.3	31.	252.1	221.6	.8	937.2	815.8	13.07	.07652
17.3	32.	254.0	223.5	1159.4	935.9	791.8	12.68	.07884
18.3	33.	255.7	225.3	.9	934.6	769.2	12.32	.08115
19.3	34.	257.5	227.1	1160.5	933.4	748.0	11.98	.08346
20.3	35.	259.2	228.8	1161.0	932.2	727.9	11.66	.08576
25.3	40.	267.1	236.9	1163.4	926.5	642.0	10.28	.09721
30.3	45.	274.3	244.3	1165.6	921.3	574.7	9.21	.1086
35.3	50.	280.9	251.0	1167.6	916.6	520.5	8.34	.1198
40.3	55.	286.9	257.2	1169.4	912.3	475.9	7.63	.1311
45.3	60.	292.5	262.9	1171.2	908.2	438.5	7.03	.1422
50.3	65.	297.8	268.3	1172.8	904.5	406.6	6.53	.1533
55.3	70.	302.7	273.4	1174.3	900.9	379.3	6.09	.1643
60.3	75.	307.4	278.2	1175.7	897.5	355.5	5.71	.1753
65.3	80.	311.8	282.7	1177.0	894.3	334.5	5.37	.1862
70.3	85.	316.0	287.0	1178.3	891.3	315.9	5.07	.1971
75.3	90.	320.0	291.2	1179.6	888.4	299.4	4.81	.2080
80.3	95.	323.9	295.1	1180.7	885.6	284.5	4.57	.2188
85.3	100.	327.6	298.9	1181.8	882.9	271.1	4.36	.2296
90.3	105.	331.1	302.6	1182.9	880.3	258.9	4.16	.2403
95.3	110.	334.5	306.1	1184.0	877.9	247.8	3.98	.2510
100.3	115.	337.8	309.5	1185.0	875.5	237.6	3.82	.2617
105.3	120.	341.0	312.8	1185.9	873.2	228.3	3.67	.2724
110.3	125.	344.1	316.0	1186.9	870.9	219.6	3.53	.2830
115.3	130.	347.1	319.1	1187.8	868.7	211.6	3.41	.2936
120.3	135.	350.0	322.1	1188.7	866.6	204.2	3.29	.3042
125.3	140.	352.8	325.0	1189.5	864.6	197.3	3.18	.3147
130.3	145.	355.5	327.8	1190.4	862.6	190.9	3.07	.3253
135.3	150.	358.2	330.6	1191.2	860.6	184.9	2.98	.3358
140.3	155.	360.7	333.2	1192.0	858.7	179.2	2.89	.3463
145.3	160.	363.3	335.9	1192.7	856.9	173.9	2.80	.3567
150.3	165.	365.7	338.4	1193.5	855.1	169.0	2.72	.3671
155.3	170.	368.2	340.9	1194.2	853.3	164.3	2.65	.3775
160.3	175.	370.5	343.4	1194.9	851.6	159.8	2.58	.3879
165.3	180.	372.8	345.8	1195.7	849.9	155.6	2.51	.3983
170.3	185.	375.1	348.1	1196.3	848.2	151.6	2.45	.4087
175.3	190.	377.3	350.4	1197.0	846.6	147.8	2.39	.4191
180.3	195.	379.5	352.7	1197.7	845.0	144.2	2.33	.4296
185.3	200.	381.6	354.9	1198.3	843.4	140.8	2.27	.4400
190.3	205.	383.7	357.1	1199.0	841.9	137.5	2.22	.4503
195.3	210.	385.7	359.2	1199.6	840.4	134.5	2.17	.4605
200.3	215.	387.7	361.3	1200.2	838.9	131.5	2.12	.4707

PROPERTIES OF AIR AT ONE ATMOSPHERE=14.7 LBS. ABSOLUTE PRESSURE.

Dry Air.			Saturated Mixture of Air and Water Vapor.		
Temp. Fahr.	Cu. Ft. per Lb.	Lbs. per Cu. Ft.	Weight of Air, Lbs.	Weight of Vapor, Lbs.	Total Weight of Mixture, Lbs.
0	11.6	.0864	.0863	.000079	.0864
12	11.9	.0842	.0840	.000130	.0841
22	12.1	.0824	.0821	.000202	.0823
32	12.4	.0807	.0802	.000304	.0805
42	12.6	.0791	.0784	.000440	.0788
52	12.9	.0776	.0766	.000627	.0772
62	13.1	.0761	.0747	.000881	.0756
72	13.4	.0747	.0727	.00122	.0739
82	13.6	.0733	.0706	.00167	.0723
92	13.9	.0720	.0684	.00225	.0707
102	14.1	.0707	.0659	.00300	.0689
112	14.4	.0694	.0631	.00395	.0670
122	14.6	.0682	.0599	.00514	.0650
132	14.9	.0671	.0564	.00664	.0630
142	15.1	.0660	.0524	.00847	.0609
152	15.4	.0649	.0477	.0107	.0584
162	15.7	.0638	.0423	.0134	.0557
172	15.9	.0628	.0360	.0167	.0527
182	16.2	.0618	.0288	.0205	.0493
192	16.4	.0609	.0205	.0251	.0456
202	16.7	.0600	.0109	.0305	.0414
212	16.9	.0591	.0000	.0368	.0368
230	17.4	.0575			
250	17.9	.0559			
275	18.5	.0540			
300	19.2	.0522			
325	19.8	.0506			
350	20.4	.0490			
375	21.	.0477			
400	21.7	.0461			
450	22.9	.0436			
500	24.2	.0413			
550	26.0	.0384			

SECTION II.—TESTING.

ELECTRICAL UNITS.

If the two terminals of a source of electrical energy, such as a battery, dynamo, etc., be joined by a copper wire or other conducting path a current of electricity will flow through the completed circuit thus formed. The current manifests itself by causing neighboring compass needles to deflect from their natural position, by heating the wire, by the appearance of a spark if the wire is broken, by chemical action in an electrolytic cell placed in the circuit, etc. Fig. 4 shows a circuit containing a primary cell and an electrolytic cell.

The Ampere.—The current flowing in the circuit may be determined by cutting the wire and connecting the severed ends to two silver plates immersed in

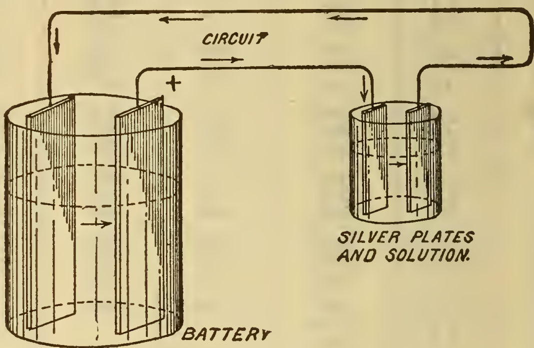


FIG. 4.

a nitrate of silver solution. It will then be found that the current in flowing through this solution carries with it silver from the positive to the negative plate, and if the battery gives a steady current the weight of silver carried over will be proportionate to the time that the current is passing through this solution. If for each second of time it is found that 0.001118 grammes of silver are carried over, then the flow of current will be one *ampere*; or the total grammes weight of silver divided by the seconds during which the current was flowing through the solution, divided by 0.001118 will give the total number of amperes flowing through the circuit during the test.

This is the way in which the unit of current flow, the ampere, was given a definite value. There are many refinements necessary to carry out the above test in order to obtain reliable results. This method is the one used to determine the true value of the ampere, but it is not useful for practical work.

The Ohm.—If there is added to the above circuit, Fig. 5, a much longer wire of the same size, and the test repeated allowing the current to flow through the silver solution from one plate to the other for the same length of time, it will be found that the current has not carried as much silver across as in the first experiment, showing that the lengthening of the circuit has diminished the current flow. This was caused by the added conductor offering resistance to the current. This is a property of all electrical conductors and is measured by a unit called the *ohm*. If the circuit had been made of No. 30 wire, Brown & Sharpe gauge, and was 9 ft. 9 ins. long, then the copper circuit would have been nearly one ohm in resistance.

The standard for the ohm is the resistance of a column of mercury 106.3 centimeters long (41.8503 ins.) of uniform cross-section, and weighing 14.4521 grammes (.5098 ozs.) at the temperature of melting ice. This is known as the "International Ohm" or "True Ohm." There are two other older standards, known as the British Associations and the Legal respectively, whose relation to the International ohm is shown in the following table.

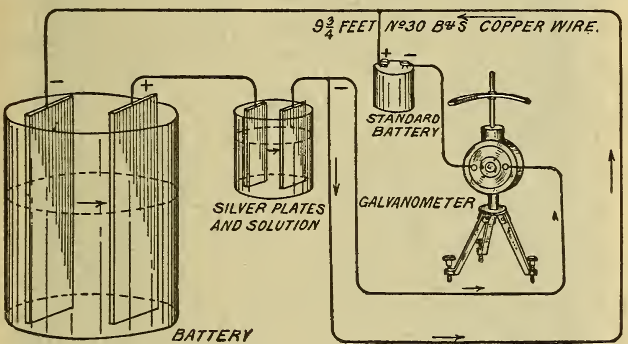


FIG 5.

INTERNATIONAL.		B. A.		LEGAL
1.	=	1.0136	=	1.0023
.9866	=	1.	=	.9889
.9977	=	1.0112	=	1.

The Volt.—Electrical pressure is required to force the current through the wire and the silver solution. Electrical pressure can be opposed by an equal electrical pressure, and there will then be no current flow in the circuit which contains the opposing electrical pressure, just as a water pressure can be acted against by an equal pressure of water, when no water will flow.

Fig. 5 shows how these pressures may be equalized electrically. A standard battery of one volt is connected in series with a delicate current indicator, known as a galvanometer; the ends of this circuit are connected to the end of the 9¾ feet of copper wire, as shown in Fig. 5, so that the electrical pressure of the standard battery circuit opposses the fall of pressure in the main circuit. Then when the loss in volts, or electromotive force, in the main circuit is equal to one volt, which

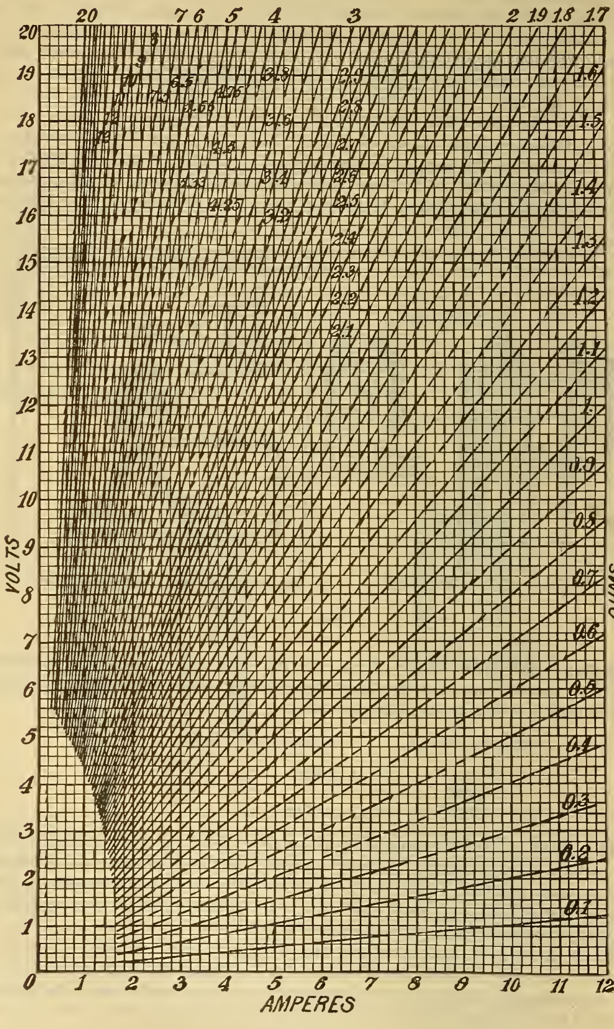

VOLTS
AMPERES
OHMS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
20
7 6
5
4
3
2 1.9 1.8 1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Fig. 6.

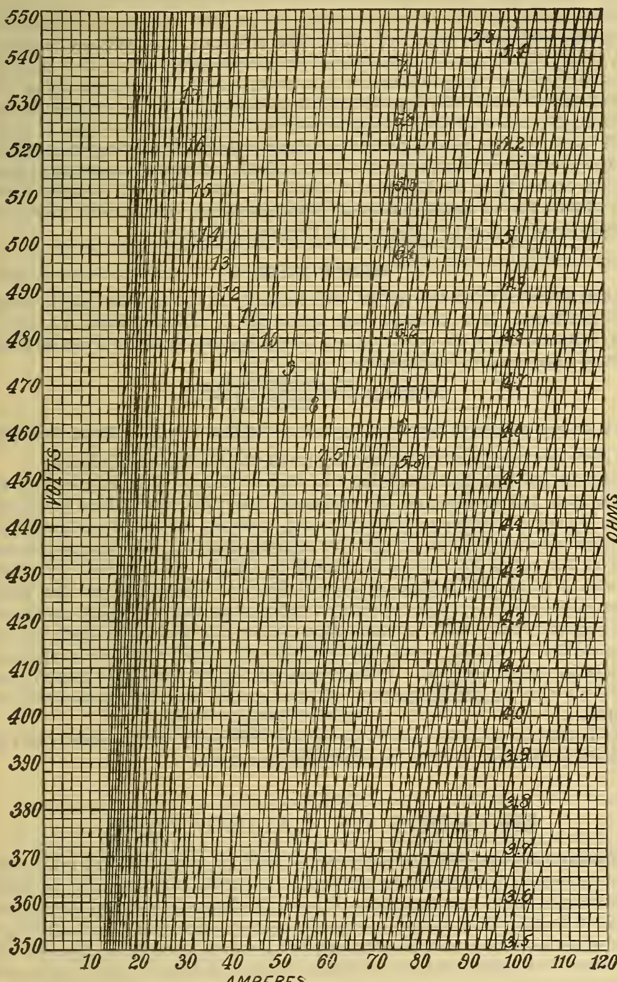

VOLTS
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
10
20
30
40
50
60
70
80
90
100
110
120
AMPERES
OHMS

Fig. 7.

is the pressure of the standard battery, no current will flow through the galvanometer circuit. Since the circuit measures one ohm, there must have been one ampere flowing through it to produce the loss of pressure of one volt. The unit of this pressure is known as the *volt*. The value of the volt is a little less than the e. m. f. of an ordinary gravity cell. It has been proved that if an e. m. f. of 1 volt acts on a circuit of 1 ohm a current of 1 ampere will flow. The ampere being fixed as that current which will deposit 0.001118 grammes of silver per second the volt, therefore, depends upon the value of the ohm and we have International, B. A. and Legal volts which bear the same relation to each other as the corresponding ohms.

The practical standard for e. m. f. is the Clark cell made according to specifications drawn up by the Electrical Congress of 1893. The cell consists essentially of pure zinc in zinc sulphate and pure mercury in contact with mercurous sulphate the e. m. f. at 15° C being 1.442 International volts.

OHM'S LAW.

Ohm discovered that the current varied directly as the pressure and inversely as the resistance. If we measure these quantities in practical units, *i. e.*, in amperes, volts and ohms, the relation given above that the action of 1 volt on 1 ohm produces 1 ampere gives us the law:

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}$$

This is known as Ohm's Law and is generally written $C = \frac{E}{R}$. From this relation, if we have any two of the quantities given, the third is readily found.

This is accomplished graphically in Fig. 6. There volts are given on the vertical lines and amperes on the horizontal lines; the radial lines giving the ohms. In any circuit where the amperes and volts are known, if we trace these two values on their respective scales to their intersection, this intersection will occur at the radial line which is marked in ohms. In a circuit for example, with 8 volts and 2 amperes, we will find the intersection on the radial line marked 4 ohms, which is the answer. Supposing that we had a circuit of 2 ohms resistance and 6 volts potential, then follow the radial line down until it intersects the 6 volts horizontal line and also the vertical line for 3 amperes, which is the answer required. In the same way, when ohms and amperes are given in a circuit, the intersection of these values will fall on the volt line required.

As in railway work 500 volts is the voltage commonly used, a scale, (see Fig. 7), for 350 to 550 volts, and 0 to 120 amperes is also given.

METHODS OF CALIBRATION.

Galvanometers.—The galvanometer is used in insulation and cable tests and in connection with the bridge method as a current indicator, also to make potential and current measurements. It is easily affected by external magnetism. It consists in general of a small permanent magnet suspended by a silk fibre, or mounted on a concave jewel having a needle point to support it. The suspension should be such that only a very slight effort is required to turn the needle. This needle is free to rotate in a spool around which are wound many turns of fine wire. A pointer, usually made of aluminum, is attached to the needle to magnify the amount of deflection. The zero position of this pointer may be fixed by the earth's magnetism, but is often controlled by a local permanent magnet.

The current flowing through the coils tends to cause a deflection, the magnetizing effect of these coils being at right angles to the suspended magnetic needle. The currents producing the deflections are related to each other as the tangent of the angles of deflection; if the needle is short and placed at the center of a circular coil the galvanometer is then called a tangent galvanometer.

In the Thomson reflecting galvanometer the readings are taken by means of a beam of light reflected from a mirror on the back of which is secured the magnetic system. When this beam of reflected light is read on a scale at right angles to the beam of light before reflection, the readings on the scale of the deflected beam are practically directly proportional to the currents deflecting the mirror.

ELECTROMOTIVE FORCE.

E. M. F. Direct Method.—To set up a galvanometer to read volts direct there is required a variable resistance-box, *A*, in series with a standard battery, *B*,

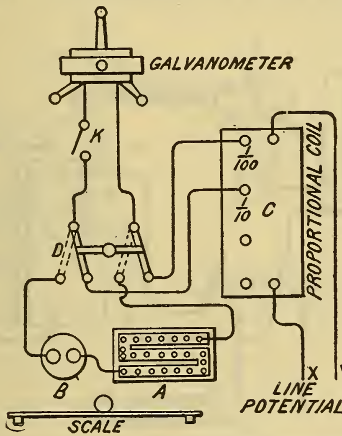


FIG. 8.

a proportional coil, *C*, a double-throw switch, *D*, and key, *K*. The connections are made as in Fig. 8.

First such resistance is inserted by box, *A*, with the standard battery (if a Clark cell is used as that standard) that it will give a permanent deflection of 144.2 divisions. Then this setting up gives for each division $\frac{1}{100}$ of a volt; throwing the switch so as to connect in $\frac{1}{100}$ of the total voltage across the proportional coil, the galvanometer will read the main potential in 1 volt per division.

A voltmeter to be standardized should be connected across the mains at *X*-*Y*. The proportional coil is generally made of No. 32 resistance wire with a low temperature coefficient, preferably platinoid. With 50 ohms per volt to be measured a proportion of 1:100 is usually used for potentials up to 150 volts, 1:500 for railway work. For reading potentials lower than the standard cell the connections are changed as in Fig. 9. The standard battery is in this case connected across the proportional coils, and the resistance changed in series with the galvanometer until deflections (142.2) are again obtained; then each deflection is $\frac{1}{10000}$ of a volt if a proportion of 1:100 is obtained from the proportional coil. The galvanometer can then be thrown over to the potential to be compared and read direct in $\frac{1}{10000}$ of a volt per scale division.

Potentiometer Method.—Where a constant potential is to be maintained during a test, the potentiometer method is more convenient. This requires a standard battery, a galvanometer, a variable resistence of a uniform wire of such a size that it will not be heated by the current passed through it; a portion of this wire is provided with a sliding contact over a scale which is divided into a thousand divisions for this length. This apparatus is connected up as shown in Fig. 10, the standard battery opposing the drop of potential along the potentiometer wire. The contact, *W*, on this wire is slid along until a point is determined at which the galvanometer shows no deflection. Then the reading on the scale will be where the drop is 1.442 volts, or the e. m. f. of the standard cell. Then the scale length

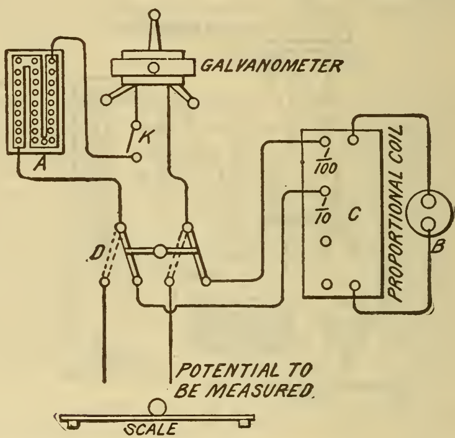


FIG. 9.

is to the total length of wire, as 1.442 is to X, or the terminal voltage to be measured. Say the scale read 2 and the total length of wire was 100, then 2 : 100 : : 1.442 : X, or = 72.1 volts. The scale can be calibrated in volts direct if the same standard potential is used for all tests.

As the Clark cell is easily injured by an excess of current it is important that a resistance of, say, 10,000 ohms be inserted in series with it. This will prevent its being short circuited through the low resistance of the potentiometer wire when the counteracting force of the e. m. f. under investigation has been removed, and the battery will not be short-circuited by the slide wire. This resistance will have practically no effect on the accuracy of the readings as there is no current flowing when balance is obtained.

Current.—To read amperes by galvanometer deflections the requirements are a shunt of known resistance, a standard battery, a double-throw switch and a variable resistance. The connections are made as shown in Fig. 11. The galvanometer is first brought back to zero by raising or lowering the current through shunt, *C*. If this shunt was .01 of an ohm and a standard Clark cell is used, the battery's potential being opposed to the drop of potential in the shunt, and if with the double-throw switch at *A*, the galvanometer shows no deflection, there are 144.2 amperes flowing through the shunt. If this current is held steady, the switch thrown to position, *B*, and sufficient resistance is added to give 144.2 deflections, then each division is equal to 1 ampere passing through the shunt. By putting an ammeter in the circuit it can be calibrated throughout its scale.

By shunts of higher or lower resistance any desired range can be secured. .1 ohm for 15 amperes, .01 ohm for 155 amperes, .001 ohm for 1,500 amperes and .0001 for 15,000 amperes give all the required ranges for checking up meters on a switchboard. The shunt can be arranged with terminals so as to plug into the switch

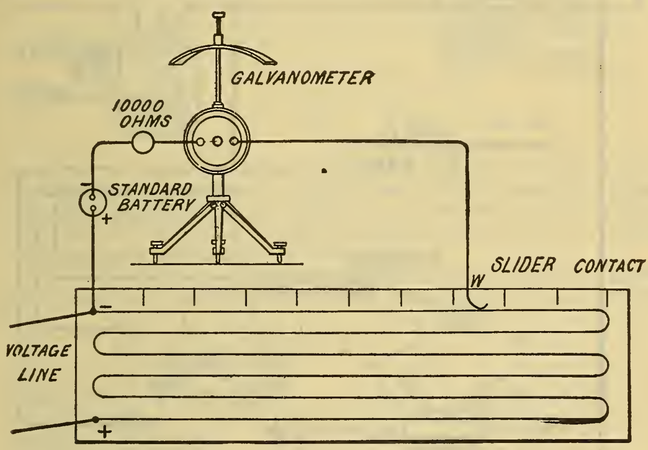


FIG. 10.

jaws when the switch is open. The galvanometer can be located at any convenient part of the building, wires leading to it from the shunt at the switchboard. If the test drop wires are connected together on the gallery and form part of the circuit between the shunt and galvanometer after the proper setting up has been obtained for the galvanometer to read amperes from that shunt the shunt can be removed to the gallery and the drop points connected to the ends of the pressure wire, and the pressure wire connected together where they took the pressure from the shunt in the testing room.

In any shunt the connection for the pressure or galvanometer wire should be well within the contacts that carry the main current to the shunt, and should never be connected to the same contact, for then the contact resistance may be included in the shunt resistance, and accurate or constant results will be difficult to obtain.

In calibrating ammeters in regular use it is best to find the average load reading, and have a single stroke bell on the gallery, the man in the testing room giving one stroke of the bell by a push button located at his hand when the current attains the agreed reading in amperes. The gallery attendant then will note the reading of the ammeter. By repeating this a few times and averaging, the error of the instrument at that point can be readily discovered.

There may be a leakage which should be removed before calibration. This is detected by first connecting to the live jaw of the switch, and noting if there is any permanent deflection of the galvanometer. If there is, it may be due to leakage

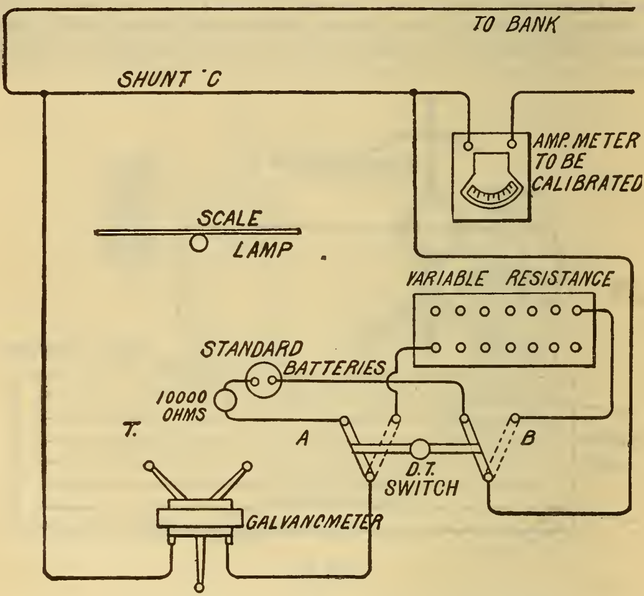


FIG. 11.

of test lines or instrument; these should be discovered and insulated before proceeding with the check measurements.

There is often considerable magnetic disturbance around a station by which the galvanometer will be influenced. This can be opposed by surrounding the galvanometer with two cylinders of ⅜ in. sheet iron separated in the middle so as not to interfere with the ray of light; two short sections of wrought iron pipe are still better. In a d'Arsonval galvanometer the magnet is stationary and the coil revolves. Thus the coil turns in a strong field and is not so much affected by changes in the magnetic condition of the surrounding space.

PRACTICAL ELECTRICAL MEASUREMENTS.

Resistance Measurements.—Where it is required to compare the resistance of a conductor with a standard, such as field or armature windings, the simplest way is to connect the resistance to be adjusted in series with a standard resistance; then on passing the same current through both resistances they have the same value when the difference of potential is the same on both. This simple method is diagramatically shown in Fig. 12.

Where the drop wires are lead out to a double-throw switch, so that the pressure on both coils can be compared quickly by throwing the switch from one side

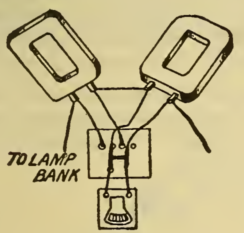


FIG. 12.

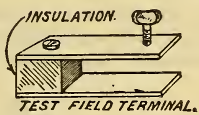


FIG. 13.

to the other, there should be sufficient current sent through the field coils to cause the voltmeter employed to read to nearly full scale in order to magnify any small differences in resistance that may exist between the standard and the coil tested. Care must also be taken that the pressure leads are distinct from the contacts through which the current is carried into the fields.

A special connection is shown in Fig. 13 for this test, for fields, for clamping the ear projecting from the field coil, the two sides of the clamp being insulated;

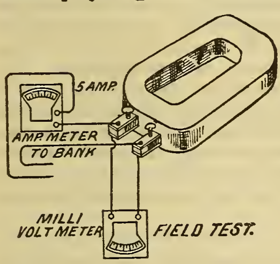


FIG. 14.

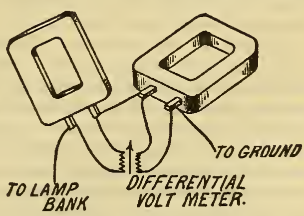


FIG. 15.

to one the current lead is attached, and to the other the lead from the voltmeter used in comparing.

It can be readily seen that in Fig. 14 the testing current is measured; then, with the drop in volts known, the volts across the coil divided by the current flowing through it will give the resistance directly in ohms.

In railway work a constant source of potential is not usually convenient, and under varying conditions of voltage it is tedious to get reliable results. For this case a method of finding the value of an unknown resistance in terms of the standard is shown in Fig. 15. Here the drop from both the standard resistance and the unknown resistance act against each other in their effort to turn a magnetic system; consequently the deflection of the magnetic system will only be the resultant of these two forces. If a differential voltmeter is used and connected as shown in Fig. 15, the deflection of the instrument will be due to the differences in potential drop in the two resistances compared; from these deflections the differences that exist between the two resistances can be determined directly, the current variation due to changing line voltage averaging out.

The Thompson method, the connections for which are shown in Fig. 16, is an improvement over the differential method, and is especially useful for the comparison of low resistances. It requires a standard resistance *A B*, a galvanometer *H*, and four equal resistances or having the ratio $\frac{EF}{DG}$. The function of these resistances, which need not be greater than 10 ohms, is to reduce the flow of current through the circuit leading to the galvanometer, so that all contact resistances can be neglected. In a conductivity bridge made for measuring copper only, *A B* can

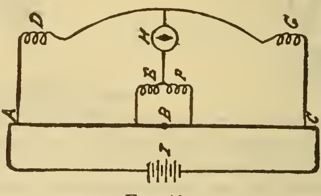


FIG. 16.

be of copper wire, which can be made interchangeable, so that a wire of fixed length and standard gauge can be compared against a wire of similar dimensions whose conductivity is to be measured. The temperature of the standard and the wire under measurement must be the same. If the wire to be measured is strung by the side of the standard, it will shortly assume the same temperature; or a more expeditious way is to pass a current through both the standard and wire under measurement to heat them, the measurements being made while their temperature is falling. If the length of the standard be divided by the length of the wire under test when a balance is obtained on the bridge, the result will be the conductivity in terms of the standard. If the standard is 100 units long, then the reading of the point of balance on the scale for the wire under test will be its conductivity in direct terms of its length.

The resistance of a wire depends on its sectional area, and the average squares of the diameters should be taken in conductivity measurements. Weighing the standard length and dividing this weight by its length in feet and also by the weight of one mil foot of this conductor, will give the true average section, and this is the method most generally employed.

There should be a very low resistance between the points of contact with the standard resistance and the rod under measurement. This is often not convenient to obtain. If the fall of potential along the standard be brought to one pair of terminals of a differential galvanometer or differential milli-voltmeter and the potential lines from the resistance to be measured, this allows of considerable resistance in the circuit between the standard and the resistance to be measured.

For approximations of conductivity in commercial work, and where a galvanometer is not at hand, a considerable length of wire may be measured off; then, by increasing the current flow, the resistance can be measured by the voltmeter and ammeter method, as described in the field resistance tests. With insulated wire, it is best to submerge the wire in water in order to determine the temperature of the copper; the current should be applied for as short periods as is possible in order to obtain reliable readings, as otherwise the heating effect will reduce the conductivity of the wire.

For temperature coefficients, and standard resistances see under "Line: Properties of Conductors."

Wheatstone Bridge.—The Wheatstone bridge primarily consists of a rheostat having two parallel circuits, one of which can be varied by cutting in

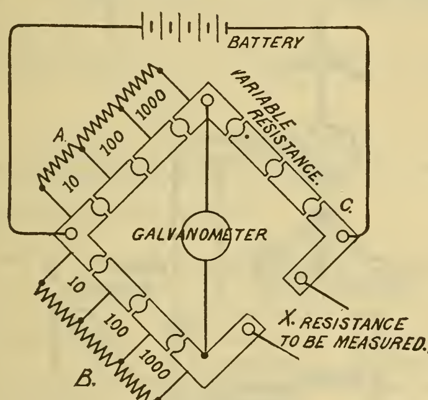


FIG. 17.

known resistances, while in the other parallel circuit is placed the resistance to be measured. If the current flow is the same through both branches of these parallel circuits, the resistance in the rheostat is equal to the unknown resistance under measurement. When on the parallel circuits equal potential points are joined by means of a galvanometer (see Fig. 17), then, when the galvanometer shows no deflection, the sections of the two paths have the proportion, $A : C :: B : X$. If X is the unknown resistance to be measured, C can be varied—if A and B are equal —until the galvanometer, H, reads zero; then the current is equally divided between the two branches, and the resistance at C is equal to that at X. A and B need not, however, be equal, but can be made of any known ratio; the same ratio will then exist between C and X when the bridge is balanced. If A is 10 and B 1000, then the resistance of C should be multiplied by their ratio, *i. e.* 100, in order to get the value of X. If X is large the value of A is made greater than B so that C may be able to balance X. The reliability of the bridge method is within the range of ½ of an ohm and 10,000 ohms. In the cases of low resistances the contact resistance where the resistance to be measured is connected to the bridge is also measured, causing a large element of error with low resistances. The current is so small that a galvanometer of high sensibility has to be used in order to determine these values with high resistances.

Insulation Resistance.—For testing high resistances an arrangement similar to that shown in Fig. 18 is found to be very satisfactory. The connections are there made for testing the insulation resistance of a cable. A known length of the cable is placed in a tank of water, and the resistance measured between the conductor of the cable and the water. About 100 cells of battery are necessary, and the unknown resistance is compared with a standard megohm by means of a Thomson galvanometer. The deflection made by closing the key, K, when the double-throw switch is in the position shown by the solid lines, may be called A; and B, that obtained with the switch thrown to the position of the dotted lines. Then $\frac{A \times 1{,}000{,}000}{B} = X$, the insulation resistance sought.

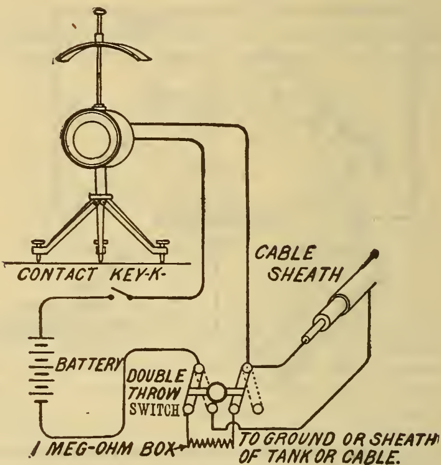


Fig. 18.

When the unknown resistance differs greatly from one megohm it will be found necessary to use a shunt with the galvanometer in order that the two readings, A and B, may be on a convenient part of the scale. The shunting ratio should be inserted in the above formulae.

INSULATION TEST BY VOLTMETER METHOD.

There are required a voltmeter, V, of known internal resistance, Fig. 19, and a source of constant potential such as M. One method is to first determine the voltmeter constant, which is obtained by multiplying the voltmeter resistance by the initial voltage used in measuring the resistance. If we open switch, K, throwing in series with the voltmeter, the unknown resistance, R, the total electromotive force will be divided between the voltmeter and external resistance in the ratio these two resistances bear to each other. Another reading will now be observed on the voltmeter. If this reading in volts be divided into the constant for the voltmeter, and the resistance of the voltmeter be subtracted from this quotient, it will give the value in ohms of the unknown resistance, *R*. Thus:

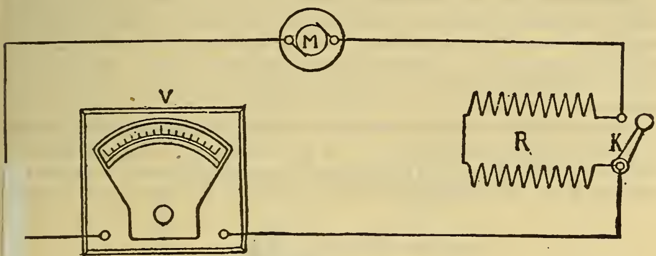


Fig. 19.

$$\text{Unknown res.} = \frac{\text{Voltmeter resistance} \times \text{initial voltage}}{\text{Volts after unknown res. is in series}} - \text{Voltmeter res.}$$

Or the following formula may be employed:

$$\text{known res.} = \text{res. of voltm.} \times \left[\frac{\text{Initial voltage}}{\text{Volts after unknown res. is in series}} - 1.0\right]$$

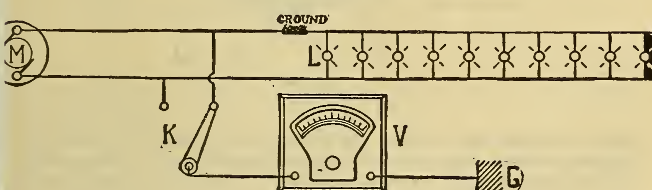


Fig. 20.

In using the voltmeter for testing for grounds, it should be connected up as in . 20 after the initial voltage of the circuit is known. It is necessary in this e to test both sides of the circuit to ground, for if there is a ground on the itive side, and the positive side is connected to ground, there will be a small or ıᴗ deflection, depending upon the difference of potential between the ground and the point of testing; whereas between the negative and ground nearly initial potential will exist, showing a nearly dead ground on the positive side of the system.

If indications show voltage to ground higher than the initial voltage at that point, the formula does not apply; it indicates that the ground is either nearer the point of generation than the point of test, or an interference with other systems.

DIRECT READING TESTING INSTRUMENTS.

The Weston Instruments.—This type of instrument, largely used in railway work, consists primarily of a light rectangular frame, *B* (Fig. 21), pivoted at the center of its long axis; around this frame is wound a number of turns of fine wire. This frame can rotate in a concentric circular space, through which passes a permanent magnetic field, and is kept in one position by the differential action of two spiral springs, *C C*, which also carry the current into it. When a current flows through the coil it tends to deflect a pointer, *D*, which is attached to this frame.

This instrument can be calibrated so as to give a scale proportional to the different currents flowing through the coil. If a voltmeter, it is connected across the leads of which the potential is required; and in series with the leads if an ammeter. (See Fig. 22 for the proper connections of voltmeter and ammeter.) A Weston

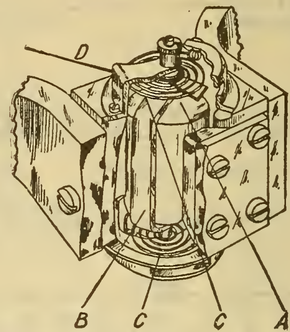


Fig. 21.

portable voltmeter for 500 volts has approximately 55,000 ohms resistance, and requires about .008 of an ampere for full scale deflection or 110 ohms per volt.

The construction of the Weston ammeter is nearly the same as that of the voltmeter except that there is a shunt in the main circuit, and the instrument takes the drop across the shunt. For small instruments this shunt is in the ammeter case, but in station types is separate. The terminals of the instrument are marked + and —, and the instrument will deflect over the scale when the positive terminal is connected to the positive side of the circuit. Care should be taken to see that the shunt leads and ammeter always bear the same shop number, for they are calibrated together, and are not interchangeable.

Nearly all station type ammeters have a constant resistance of .305 ohms; the current required to give full scale deflection averages .075 amperes. The resistance of the instrument and its leads being known, the length of the cable required as a shunt for the ammeter can be found in this way. The length of main or bus bar, *L*, is equal to the product of the resistance of the meter, including leads, multiplied by the current, *C*, required in the instrument to give full scale deflection, divided by the resistance of a square inch of copper 1 foot long, *R*. This dividend is again multiplied by a dividend obtained by dividing the cross-section of the bus bar (or cable) in square inches, S, by the maximum current, C, to be measured on the bus bar (or the full range of the ammeter), or $L = \frac{V \times C}{R} \times \frac{S}{C}$. If the resistance, in case of a cable, is accurately known per foot, then the proper resistance, R, to be included between drop points can be found by multiplying the resistance of the instrument and leads by the current required by the instrument; dividing this by the maximum current to be read by the instrument gives the resistances required, or $R = \frac{V \times C}{C}$, which resistance divided by the resistance per foot of the cable to be used as the shunt, gives the length of cable required to give the correct drop for the meter to read amperes. This determination can be checked by a

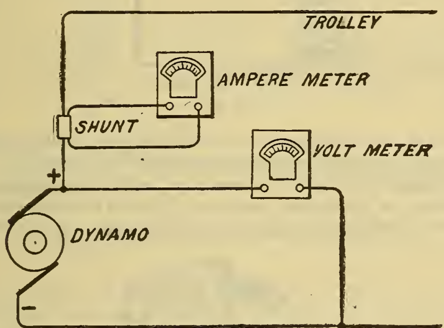


FIG. 22.

reading on a meter temporarily in series with the feeder or bus bar on which the shunt has been adjusted.

It is often required to know the current over a number of feeders from time to time without the expense of a separate ammeter on each feeder, especially so on ground return feeders. Permanent drop points can be adjusted on the cable at some convenient place where it enters the station, and another a point at such a distance as to give the correct drop; then the ammeter with the leads with which these shunts were adjusted to read correctly, can be connected to the drop points, and the current read on any feeder desired.

POWER MEASUREMENTS.

In order to get the power delivered to any electrical device, the constant current flow in amperes multiplied by the volts lost through the device will give the watts consumed. As 746 watts are equivalent to one horse-power, the product divided by 746 will give the horse-power absorbed. The continuous power taken can be determined by multiplying instantaneous readings of volts and amperes when both volts and amperes are steady, but this method does not give reliable results. Where these are varying, as in a railway load, a direct reading wattmeter should be used. Here the main current is carried through the instrument, and also the potential across the terminals of the current under measurement; the combined efforts of these two currents are calibrated on a scale from which the instantaneous watts can be read directly. (See Fig. 23 for the connections to be made with a

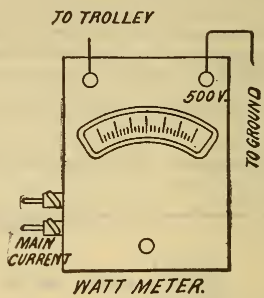


FIG. 23.

wattmeter.) But these readings must be multiplied by the length of time in minutes in order to get the continuous record of output in watt minutes.

For a continuous test of power consumption, such as in a dynamo or a street railway equipment, an integrating wattmeter giving a summation of all energy delivered, is used. This meter is practically a motor whose speed varies directly

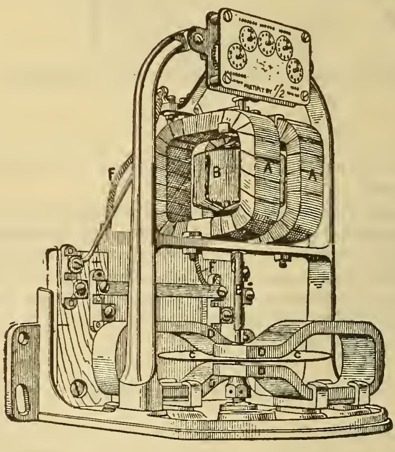


FIG. 24.

as the energy passing through it; and the resultant revolutions of this motor are recorded on a summation dial which can be read directly in watt hours.

In Fig. 24, *A*, *A*, are the field coils; *B*, armature coils; *C*, *C*, copper disc; *D*,*D*, retarding magnets; *E*, spindle; *F*, *F*, wires leading through armature coil.

TESTS ON ELECTRIC RAILWAY SYSTEMS.

TEST FOR RESISTANCE OF INDIVIDUAL BONDS.

The instruments required for this test are: one milli-voltmeter with zero in the center, two resistances, one-half ohm each, a stand like Fig. 25, or a straight edge like Fig. 26. In testing for individual bonds with the stand shown in Fig. 25, two fixed contacts bridge the rail-joint at a distance of about 12 ins. apart, and

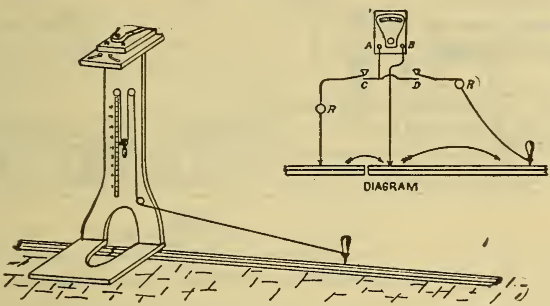


FIG. 25—STAND FOR INDIVIDUAL BOND TEST.

the variable contact is moved along the rail until a balance is obtained on the milli-voltmeter. The scale of the stand will then read, when the keys *C* and *D* are both depressed, the resistance of the joint in terms of the rail length; that is, the length of the solid rail, which has the same resistance as the joint.

To determine the current flow in the rail, carry the cord out until it registers 10 ft. on the scale, and press down key *D*; then the current in the rail in amperes

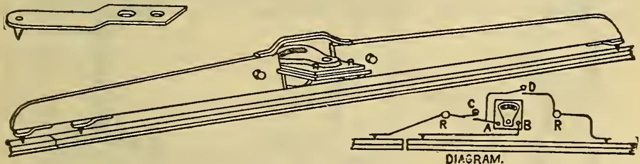


FIG. 26—STRAIGHT EDGE FOR INDIVIDUAL BOND TEST.

will be the millivolts, multiplied by the weight of the rail in pounds per yard, divided by 8.7.

This formula applies to steel rails not exceeding .49 of 1 per cent manganese. With the straight edge shown in Fig. 26 the voltmeter reading is first taken with *D* only depressed; then with both *C* and *D* depressed. The ratio in readings will then give the resistance of the bond as compared with that of straight rail. As usually constructed, the distance between the contact spanning the joint is 1 ft., and that between the contacts on the solid rail is 6 ft. This gives a ratio of 6 to 1 and makes the bar about 7½ ft. long.

This test provides a more rapid way of determining defective rail-bonds than that given in test No. 25. The apparatus required is one special truck, made up of two pairs of old wheels and boxes, with one axle cut and insulated. The two axles should be insulated from each other by making the side framing of wood, and attached to this side frame should be four metallic track brushes each located

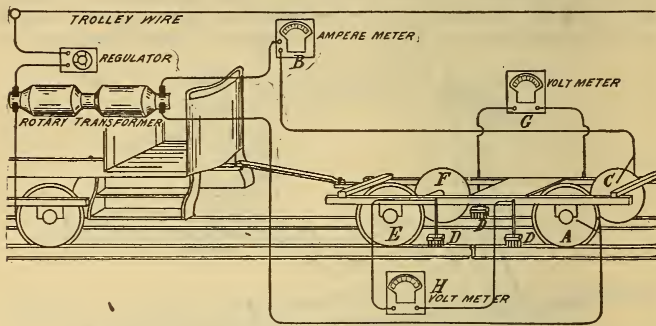


FIG. 27—TRAILING TRUCK FOR TESTING BOND RESISTANCES.

as shown in Fig.27. The other apparatus required is two voltmeters reading 3 volts full scale, one ammeter reading 200 amps., one motor dynamo 500 volts to 5 volts, and 200 amps., and a regulator to control the speed of the motor-dynamo. The connections are shown in Figs. 27 and 28.

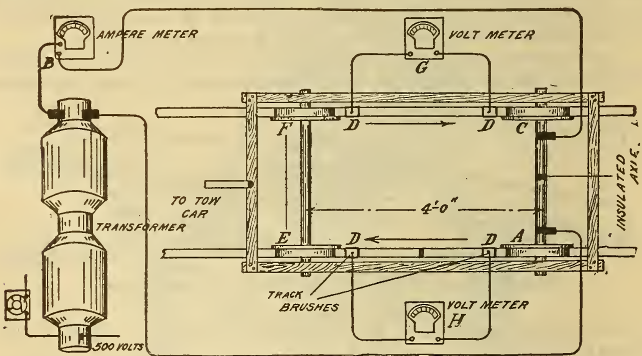


FIG. 28—PLAN VIEW OF TRAILING TRUCK SHOWING CONNECTIONS.

The current from the low-potential side of the motor-dynamo is taken to wheel *A* of the pair of wheels having an insulated axle. These wheels should be located furthest away from the tow-car. The metallic truck brushes are located as shown at *D D D D*, and should be as far apart as possible, but between the wheels of the truck. The path of the measuring current is from wheel *A*, through the rail to wheel *E*, then across the continuous axle through wheel *F*, then along the rail back to the other wheel, *C*, which is connected to the opposite brush of the low-voltage dynamo. The voltmeters *G* and *H* measure the drop between the track brushes on each side of the truck. The testing truck is towed along by a car, in which are located the measuring instruments, the motor-dynamo and its regulator.

An examination of Fig. 29 will show how the voltmeter readings, as taken in different positions of the trail car, will determine the condition of the individual bonds. Assume a uniform weight of rail and the joints staggered. Then in Position 1 (Fig. 29), the current passes through joint *B* and back through rail *A*. The difference in the readings between the two voltmeters on the *A* and *B* sides of the car will give the resistance of joint *B*, as compared with solid rail. In Position 2, both voltmeters should read alike, if there is no cross-bonding across the four tracks. In the case of cross-bonding the current would be shunted around through the rails on the other track, and all of it would not go directly back through the opposite rail of the first track. The current will be diverted through the cross bonding, and the voltmeter readings will be less than that

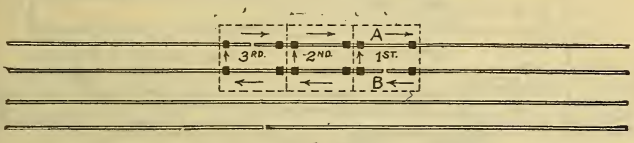


FIG. 29—DIRECTION OF CURRENT FLOW.

required by the amperes flowing, but the ratio of the voltmeter deflection to current flowing will indicate the conductivity of the cross-bonding work, as compared with the cross-bonding made by the car and test truck. No car should follow the testing truck within 1000 ft. If the road is in operation and the rails are carrying current, the side of the track carrying the current from the motor-dynamo will be increased in voltage when the test current and working current flow in the same direction, and when the test current is flowing against the current in the rails it will be decreased in voltage. When the drop in the rail is zero the current flowing from the motor-dynamo will be equal to that flowing in the rail.

By carefully watching the voltmeter as the car proceeds, joints can be measured in the way described at the rate of about 4 miles an hour. As the bad joints are found they can be marked by injecting whitewash on the roadway, and can then be marked permanently for repair later.

AGGREGATE BOND TEST FOR A SECTION OF TRACK.

The instruments required for this test are one ammeter reading 200 amps., one voltmeter, 30 volts, one water-barrel rheostat, one snap switch for 150 amps., and 500 volts, and one long pole to reach the trolley wire. On a motor car place the water-barrel rheostat, in which have two iron plates about 14 ins. x 24 ins., separated by slats. Connect as shown in Fig. 30. Use bicarbonate of soda in the water rheostat, so that with 500 volts about 140 amps. will pass. Connect the snap switch on the trolley side of the rheostat and the ammeter in series. Have the circuit breaker opened in the station (by prearranged signals) on the feeder supplying the section of trolley over the track to be tested. With a No. 18 wire connect all four tracks with the dead trolley. It is advisable to be sure first that the trolley is dead by reversing the trolley-pole to the dead trolley; if the lamps do not light, the section is open. Then the determination of the track return resistance can be made by first reading the volts between this dead trolley and the track, as shown by the voltmeter, and by dividing the reading thus obtained by the amperes flowing in that rail.

The relative resistance of each track, as compared with the total circuit, can be determined by the drops on a rail length of each track. The drop between each rail and the dead trolley can be taken. The drop between the different rails will give the cross-bonding conditions. Where there is a loop or there are intersecting tracks which offer other paths for the return current than the one under test, the current flowing back over the section under test has to be measured by drop on rail lengths. The current in the two paths beyond and behind the test car is inversely proportional to the resistances of these two return circuits. This gives the individual rail return resistance, and the collective rail resistance over

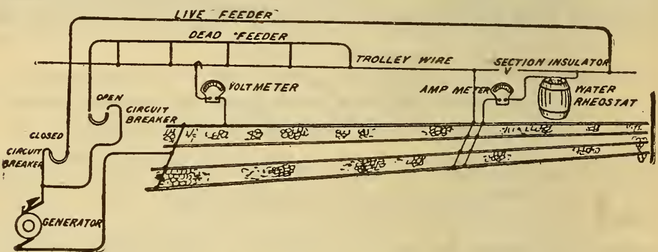


FIG. 30—CONNECTIONS FOR AGGREGATE BOND TEST.

the section under test, the cross-bonding conditions and the value of the tested track in its ratio with any other return circuit. If one rail is carrying less than the other, its bonding is poor, but effective cross-bonding with no current indicates one or more open rail joints between cross-bonds.

TEST FOR CURRENT FLOW IN WATER PIPES.

The instruments required for this test are one voltmeter reading 5 volts, one ammeter reading 15 amps., 600 ft. of No. 6 B. & S. cable, 600 ft. of No. 10 B. & S. cable, two plug clamps like shown at *A*, Fig. 32, and one portable reel, shown at *B*, provided with a commutator, as shown at *C*. The reel should have a shelf, to which the instruments and switch are secured.

If two adjacent water-plugs, which are on the same line of pipe, are connected together electrically, as in Fig. 32, through an ammeter and if a current is flowing through the pipe, a part of the current will be diverted through the external ammeter circuit *A-B* when switch *E* is closed. To determine the current flow in the water-pipe the following readings will have to be taken: volts with switch *E* open which can be called V_1.

Volts with switch *E* closed, which can be called V_2, also amperes flowing, *A*. If we call the normal current flow in the pipe *X*, then $X : A :: V_1 : V_1 - V_2$. This is approximately correct. The results may be unreliable from the following causes: First, the two plugs may not be on the same water main, then the ammeter leads form a jumper between these two pipes, and there is a very slight change of voltage for considerable current flow, and apparently a very low resistance is shown. A number of adjacent plugs along a street should be measured in order to get the average current value. A bad pipe joint will show high voltage

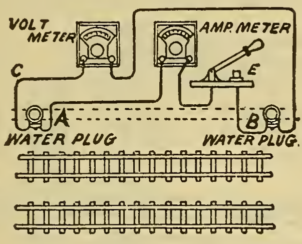


Fig. 31—diagram of connections.

on open switch and large current with small drop in voltage when switch E is closed. Again, there may be considerable resistance in the lateral pipe connecting the plug to the main. When this is the case, the closed circuit volts will be low, no perceptible, or very little, current will flow, and adjacent pipe section readings will not approximate the values which they should show.

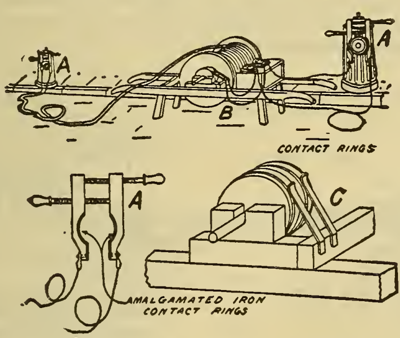


Fig. 32—apparatus required in this test.

TEST FOR DROP ON GROUND RETURN CIRCUITS.

The apparatus required is the same as in test (Fig. 30). First open the circuit-breaker in the station and ground the feeder to be tested by connecting it to the negative bus by small fuse wire. The volts read at A, divided by the current at B, will give the ground return resistance, including all paths to station. If the return is metallic only, the current will follow Ohm's law; if the return is partly metallic and partly earth the return resistance will fall with an increase in the measuring current. The most convenient way is to use the longest feeder for a pressure feeder, and employ a tapping clamp for the pressure wire, like that shown in Fig. 34.

The relative values of ground returns can also be determined by employing the trolley current. This test requires a five-way shunt board, as shown at *C*, Fig. 35, and an ammeter, *A*, to read the main current, and capable of recording 200 amps.,

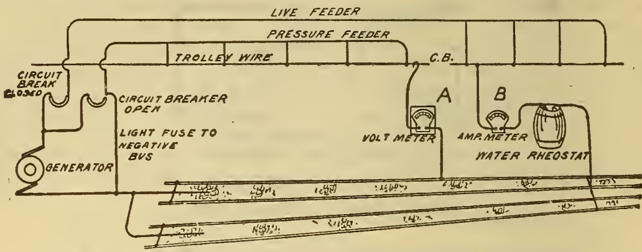


Fig. 33—Connections for testing the drop on ground return circuits.

switch rheostat, one plug clamp, and four track clamps and leads and an ammeter, *B*, to read off the divided circuit shunts. When the current from the trolley wire through the rheostat reaches the shunts, *C*, *D*, *E*, *F*, *G*, it splits up in proportion to the resistance of these various circuits. The conductivity of each circuit can then be obtained by seeing the proportion of the current taking each path, as shown by the readings of *A* and *B*. This method, however, short-circuits the ground resistance between rail and pipe and the apparent pipe conductivity is thus lower than the actual pipe return.

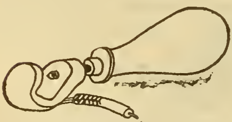


Fig. 34—Tapping clamp.

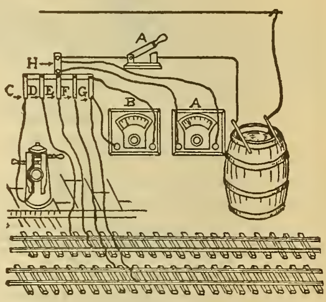


Fig. 35—Method of measuring relative values of returns.

TEST FOR LOCAL EARTH RESISTANCE BETWEEN PIPE AND RAILS.

The instruments required are one ammeter reading to 20 amps., one voltmeter reading to 20 volts, one calibrated rheostat of 20 ohms with capacity of 20 amps., one water-plug connection, 40 ft. of flexible table, No. 6 B. & S.; 40 ft. of No. 10 B. & S. cable and track clamps.

Connect all rails together and in series with the rheostat and ammeter, as shown in Fig. 36. Then connect the other terminal of the rheostat to a water-plug, then to the rail through the voltmeter. The readings to be taken are as follows: First, read the voltmeter with ammeter circuit open, then close the ammeter circuit with no resistance in rheostat and read volts and amperes; then

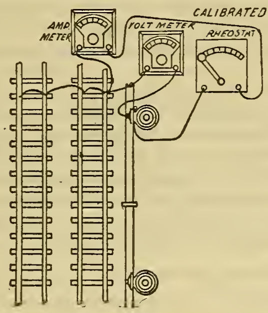


FIG. 36—DIAGRAM OF CONNECTIONS FOR TESTS.

insert enough resistance in the circuit by means of the rheostat, to make the voltmeter read just one-half the average volts of the previous voltmeter readings. Then the resistance inserted in the rheostat is equal to the resistance between the track and the water-pipe system. While this conclusion is not absolutely true, it gives results nearer the truth than the daily variation of resistance between water-pipes and the rail-return circuit.

The practical purpose of this test and that of Fig. 31 is to locate metallic connections between rails and subterranean pipes, to determine neutral territory

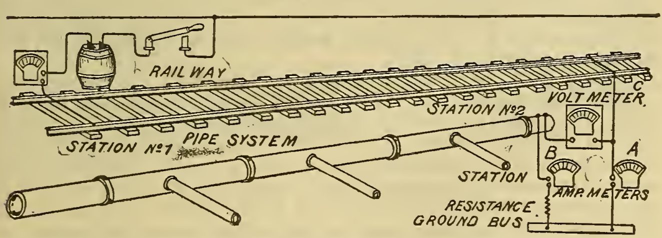


FIG. 37—DIAGRAM OF CONNECTIONS FOR TEST.

where there is no tendency for the current to leave the rails or pipe system, and to localize the districts where the current leaves the water-pipe system and enters the rails; this is the district where destructive electrolysis may occur.

The above tests will not give all the necessary information regarding electrolytic conditions to indicate the correct remedy. The next test (Fig. 37) is also necessary.

TEST FOR RELATIVE CONDUCTIVITY OF RAIL AND PIPE RETURNS.

The instruments required are a water rheostat, ammeter reading 200 amps., and a quick-break switch, all of which are mounted on a test car. In the station, the ground return of the system is broken, and an ammeter reading some 200 amps. is in the circuit from the rails to the bus. Another ammeter is inserted between the water-pipe system and the ground return bus, and a voltmeter is inserted between the water-pipe system and the rail return connection, as shown in Fig. 37.

The following precautions are necessary: There should be no load on the railway system except the artificial load thrown in on the test car. This can be readily detected, since there should be no reading on ammeter *A* when the controller on the test car is open. It is necessary to introduce a resistance in the ammeter lead between the water-pipe and the ground return bus, so that the voltmeter readings will not be below their normal values, unless the negative bus bar is connected normally to the water-pipe system at the station. In this case such connections must be removed in making this test, but no resistance need be inserted.

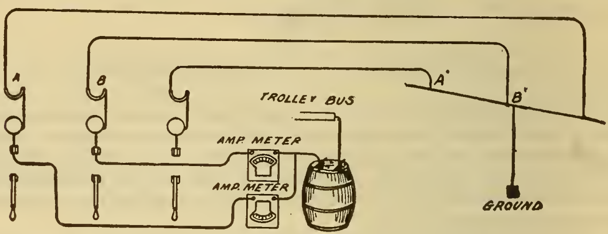


FIG. 38—DIAGRAM OF CONNECTIONS FOR TEST.

Different points should be selected along the route at which to make tests. These points should be numbered in consecutive order in such a way that the test car will pass them in a regular order, marking them up on one track and down the other in double-track roads.

The test car is then brought to a stand at station No. 1, and the load is put on through the rheostat by means of the switch, rising gradually from 100 to 200 amps. This current can pass back to the station through two routes, one through ammeter *A* and one through ammeter *B*. The reading of ammeter *A* are to those of ammeter *B*, as the conductivity of the rail return system is to that of the pipe circuit. The readings of voltmeter *C* will rise and fall, depending upon the resistance between the rails and earth return in the locality of the station. By plotting out these relations throughout the railway system, those parts of the system which have to be protected may be clearly located by studying the conductivity of the two systems at different points. Metallic connections between the railway and the water-pipe can also be readily located in this way.

TEST FOR LOCATION OF GROUNDS OR LEAKS.

This test requires the use of the water-barrel rheostat, the two ammeters and the connections to fit the jaws, as in the previous test. The connections are shown in Fig. 38. If the leak is considerable the feeder ammeters will show its approximate location by the relative readings, but if the current is slight, low reading ammeters will have to be used.

As an example, suppose it be found that the resistance of feeder *A* was .15 ohms, that of feeder *B* .3 ohms, and that of the trolley wire between *A* and *B* .25 ohms; the total resistance of this circuit would then be .7 ohms. It will be noticed that the current can take two paths to the leak, but the resistance of the leak is common to both circuits, consequently the current will pass to this leak through the circuits in the proportion that the resistance of these two circuits bear to each other. Suppose the readings on the two ammeters show that for the circuit *A* 20 amps. pass, and that for the circuit *B* 12 amps. pass, the total current flow being 32 amps. Then for *A* we have the proportion, 32 amps. is to 20 amps., as .7 ohms (the total resistance of the circuit) is to *X* (the resistance to the point of leak). For the *B* circuit we have 32 : 12 : : .7 : *X*. Solving this gives for the circuit through *A*, .437 ohms, and through *B* .2625 ohms. Subtracting the known resistance of *B* feeder from the resistance of *B* circuit gives .0125 ohms, from the end of *B* to the ground, and subtracting from the *A* circuit the resistance of *A* feeder

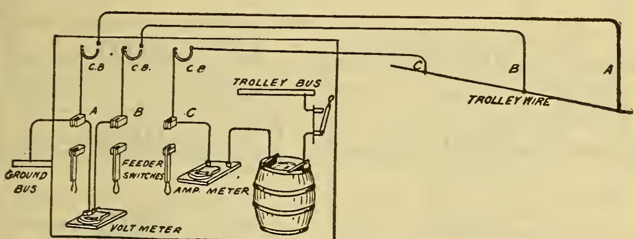


FIG. 39—DIAGRAM OF CONNECTIONS FOR TEST.

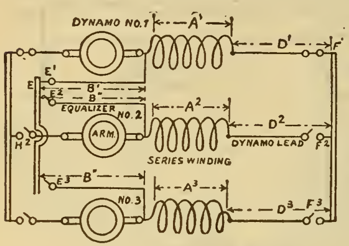
(.437—.15) leaves .287 ohms, beyond the end of *A* feeder to the ground. If we know that the length of the trolley from *A* to *B* is, say, 2400 ft. and uniform cross section we may divide the resistance of this length by its length, or .3 ohms by 2400 ft., which is equivalent to .000125 per foot. If this resistance per foot is divided into the found resistance from *B* to ground, or .0125 ohms. we have 102 ft. from *B*. The same calculation on the *A* circuit would give 2296 ft., which is the distance from *A*. Any other leak on the system can be located by removing the ground connection from the ground bus and applying it to any other feeder terminal with all the feeder switches open. Any connection to each independent section will then show if there is a leak.

TEST FOR LINE RESISTANCE.

The apparatus required for this test is a water rheostat, an ammeter reading about 100 amps., a voltmeter reading about 250 volts, and two connectors that will fit the jaws of a feeder switch and be capable of carrying a load of about 50 amps. The connections are shown in Fig. 39. It will be noticed that the current passes from the water rheostat through the ammeter, out through feeder *C* to C^1, along the trolley line to A^1, and back to the ground bus at the station, through the jaw of switch *A*. Now if the voltmeter pressure between *A* and *B* and the current flow are known, then the volts divided by the current, will give the resistance of the feeder *C*, and that of the trolley line from *C* to B^1. Similarly the pressure between B and C, when divided by the current flow, will give the resistance of the trolley wire from B^1 to A^1, and the resistance of feeder A. By shifting the ground bus to the jaw of the switch for feeder B and again putting the load on the system, the volts dropped between A and B, divided by the current flowing, will give the resistance of feeder B. This principle can even be applied to complicated overhead feeder systems, which can be temporarily tied together by putting jumpers around the line circuit breakers, and all the electrical data, from the overhead line to the power station can be determined.

TEST FOR EQUALIZATION OF COMPOUND WOUND GENERATORS.

The circuits that affect the mutual compounding of generators, working in multiple, are the series winding A^1, equalizers B^1, and generator leads D^1, Fig. 40. To operate compound wound generators in multiple so that they will carry varying loads in proportion to their outputs the following rules must be observed:



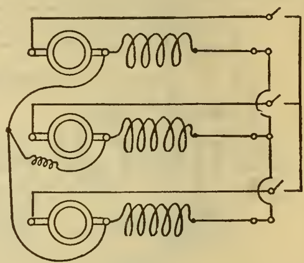


FIG. 40—EQUALIZER AT SWITCHBOARD. FIG. 41—EQUALIZER AT GENERATOR.

that the resistance A^1, B^1 and D^1 constitute those resistances which are involved in properly equalizing the generators, and that the conductivity of the equalizer circuits for each generator must bear the same ratio to the conductivity of all equalizing circuits in multiple, as the output of each generator bears to the total output of all generators.

First, consider equalizing generators of the same design and output. The usual method of connecting is shown in Fig. 40. To make these generators work properly together it is necessary that the resistance between the equalizer bus E and bus F be the same for all generators, and that bus E should not have any appreciable resistance. Or the equalizers may be directly tied together, as in Fig. 41. If generator No. 1 is on the bus, and it is required to throw generator No. 2 in parallel with it, equalizer switch E^2 (Fig. 40) is thrown. This has no effect until switch F^2 is thrown. Then the current flows through the series-coil of No. 2 and is diverted from the series winding of the operator generator. The amount of current thus diverted depends on the ratio of the two parallel circuits.

When generator No. 2 is brought up to speed and bus voltage, switch H^2 is thrown in, and the current gradually fades out of the equalizer connection as generator No. 2 takes its portion of the load. The equalizer connection has the function of maintaining the same voltage at the terminals of the two machines, and there will be no tendency to cross-compound.

Where similar dynamos are located at different distances from the switchboard their equalizing connections must all be equal in resistance to the leads of the generator farthest distant, if the same current density has been figured on all the leads. In equalizing generators of different designs and outputs the same relation of equalizing circuits must exist between the different machines as in similar one, except that the resistance of the different equalizer circuits decreases as the output of the generator increases. In other words, the drop between the equalizer bus-bar and series bus-bar must be the same for all units working in parallel, where fully loaded; or the maximum current delivered by a unit, multiplied by the resistance of its equalizer circuit, must be equal to a constant, which is $CR = E$.

Two methods of connecting equalizers are recommended. In one the equalizers are taken back to the switchboard (Fig. 41), and in the other the equalization

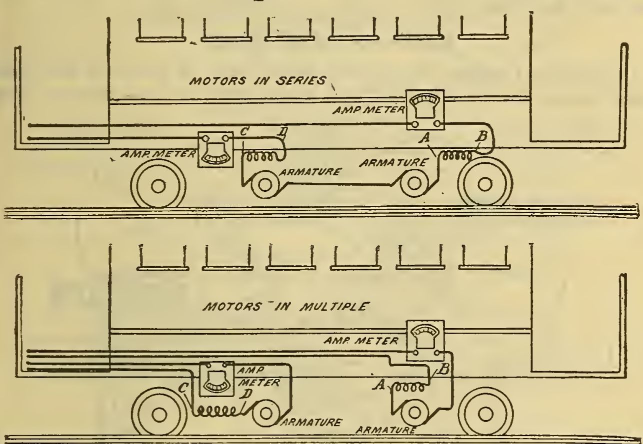


FIG. 42 AND FIG. 43—TESTING FOR THE EQUALIZATION OF MOTORS.

is at the generators. The only advantages gained by the first method is that the equalizing connection is under the control of the switchboard attendant, but as the resistance of the equalizer leads is thereby increased the machines do not tend to divide the load so readily between themselves, and act more as independent machines in multiple.

TEST FOR EQUALIZATION OF MOTORS.

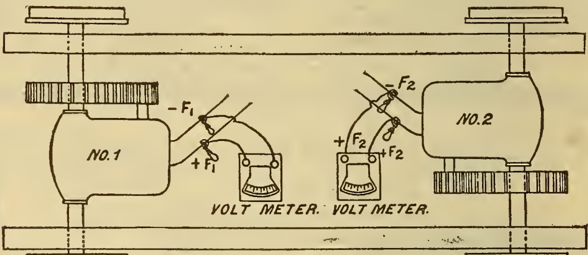
The instruments required in the case of an ammeter test are two ammeters, both reading to 150 amp., inserted in the armature leads, as shown in Figs. 42 and 43. In the case of a voltmeter test, the instruments required are two voltmeters reading 30 volts, tapping across the fields at *AB* and *CD*.

In a two-motor equipment it is necessary for the maximum efficiency of the equipment that the two motors perform the same duty. To determine whether they are equal or not it is necessary to put an ammeter in each motor circuit, or a voltmeter reading 30 volts across each field (Fig. 44), and if the motors are doing uniform duty in the multiple position the drop across the fields will be the same at different speeds.

With a wide gap between the armature and fields in one motor and a narrow gap in the other and the motor resistance high in the motor with the small gap, the load carried by these two motors will vary with the speed of the equipment. If the two motors are fed through a water rheostat in the multiple position, both ammeters, in the case of the ammeters' test, and voltmeters in case the drop is taken across the fields for equalization, should register the same amount, provided the motors have been equalized as to the resistance of the two motor circuits when the equipment is stationary. But it does not necessarily follow that the motors, which have been equalized when stationary, remain so in operation, for this depends upon the field density. So motors can be tested for equalization only while operating.

TESTS ON EQUIPMENTS.

Location of Faults.—To locate equipment leaks, tie down the trolley pole out of contact with the trolley wire, open the controller and take off cover, bring



VOLT METER EQUALIZING TEST.

Fig. 44.

the negative end of a 500 volt voltmeter lead to the platform with an insulated handle, one end of which enters the flexible test cord, and the other terminates in a sharp phosphor-bronze point.

With the controller off and reverse open and both head switches closed, first make contact with T as marked on the different types of controller diagrams, Figs. 45, 46 and 47. If there is no deflection of the voltmeter, it means no ground. A deflection will occur if lamp circuit is closed, or if there is a leak through the car wiring. This test should show over a megohm, and the deflection should be under 20 volts with 500 volts initial testing current.

With a 60,000 ohm voltmeter, by taking out the lamps the ground can be located in the lighting circuit; a lightning arrester ground will then show, or if there is a ground in the fuse box. If the trolley stand is grounded, the grounds will go off on opening the head switches. On disconnecting the lightning arrester ground, if the ground goes off, the spark gap is probably short-circuited.

Grounding with voltmeter terminal on R_1 in K_2, the controller gives rheostat ground only. In No. 14, + 2 gives one resistance of rheostat only. In type G, + 1 gives both rheostat and field of No. 1 motor, which have to be separated at contact 2-F_1 + and tested separately. For the armature of No. 1 motor, AA_1 on the reverse; for K_2, A_1 + on the reverse. For No. 1 armature and rheostat in No. 14 controller, A_1 + on the reverse in Westinghouse type G; F_1 for field of No. 1 motor for ground in K_2; F_1 + for field of No. 1 motor for ground in No. 14.

Field of No. 1 tested with rheostat in G controller, Armature No. 2 motor in K_2 controller, test from A_2. Armature No. 2 motor, ground connection has to be removed, or brush taken out of motor on ground side in No. 14 controller and test from A_2. A_2 will give ground from reverse of No. 2 armature in type G. For field No. 2 motor, ground connection has to be taken off ground to test insulation in K_2, and test from F_2.

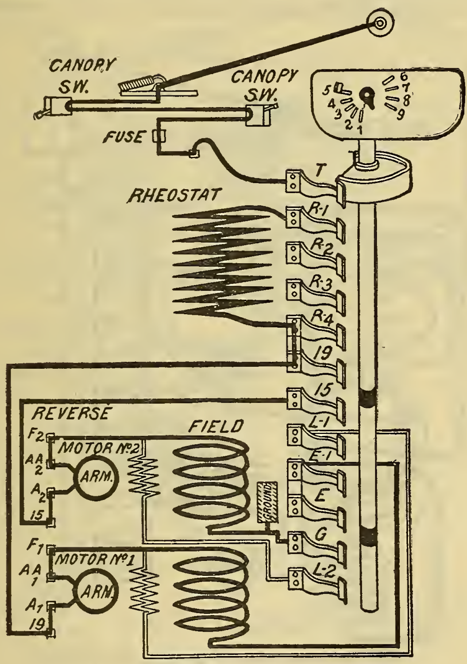


FIG. 45.—K_2 GENERAL ELECTRIC CONTROLLER.

F_2 + on the reverse gives ground on No. 2 field, Westinghouse No. 14. F_2 + on the G controller gives field ground of No. 2 motor in controller.

For test to ground on any contact finger to controller base, remove connection to that finger and test finger for ground.

For ground on any contact ring or cylinder, test the different rings with controller open.

To save time and calculation the resistance in series with the voltmeter can be figured once for all, and a scale pasted on the glass of the voltmeter marked to correspond with the resistance in series with the voltmeter to give the different deflections; or curves can be laid out between the volts deflection and resistance for several different initial voltages, and in this way volt readings can be easily reduced to insulation resistances.

Equipment Resistances from Trolley to Ground.—For this test is required a 10-ampere lamp bank which can be made up of lamp sockets and located anywhere in the car barn or repair shop. A convenient arrangement for this is shown in Fig. 48. Using 4-watt lamps will give better results with varying current. Locate the lamps at least 6 ins. between centers both ways, so that their heat will not reduce their life; 16-candle-power blackened car lamps will answer as well as new lamps. In series with the 8 banks of 16 use a rheostat of 4 amps.

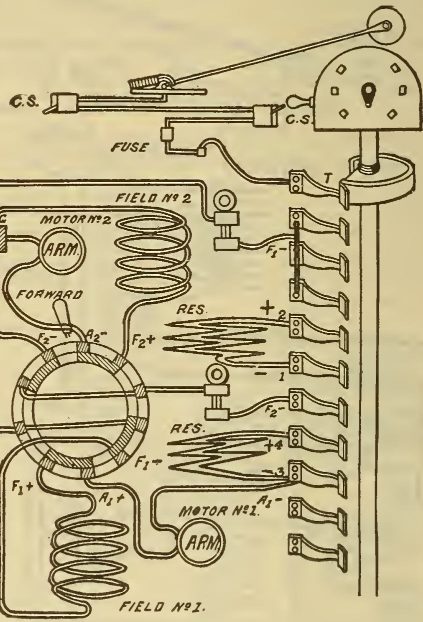


FIG. 46.—WESTINGHOUSE 14-CONTROLLER.

capacity and 15 ohms resistance, and about 20 steps, so that the test current can be adjusted to exactly 10 amps. through the ammeter.

To connect into the equipment, pull down the trolley pole and hook over it the connecting hook, shown in Figs. 49 and 53. It is best to use a separate ground connection to a ground return feeder if possible, for the cars running on the main track will vary the ammeter readings, making it necessary to continually adjust the rheostat in order to keep the ammeter at 10 amps. This ground connection is best made by inserting between the brake shoe and wheel a thin copper plate (Fig. 51) to which the ground lead is attached. If a voltmeter reading 150 volts together with a 15-volt coil, are connected between the trolley lead and ground lead, and there are 70 amps. flowing through the equipment, then each volt division will be $\frac{1}{10}$ of an ohm in the circuit and by the drop.

The resistance for each step of the controller can be read direct by adjusting the current to 10 amps. by means of the rheostat and bank switches.

The following is given as the average reading in ohms for some of the equipments ordinarily found in practice after operating for some time. These results were obtained by the use of rheostat, Fig. 53.

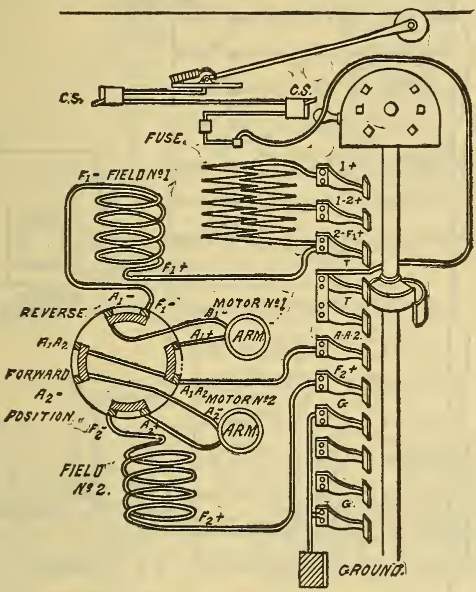


FIG. 47.—WESTINGHOUSE CONTROLLER.

Type Motors.	Type Controller.	Equipment Temp. Fahr.	Average Total Resistance on each Step.								
			1	2	3	4	5	6	7	8	9
2-12 A	28 A	65 degs.	7.20	4.93	3.56	2.87	2.91	.78	.78	....	....
2-12 A	K_{10}	67 degs.	6.80	4.32	3.55	3.10	2.57	2.41	1.69	1.07	.78
2-G E 800	K_2	75 degs.	8.68	4.17	2.70	2.16	2.02	2.63	1.13	.63	.585
Type C Steel	K	....	2.64	2.45	2.10	1.40	2.13	1.25	.30	....	....
2-No. 12 West.	D	62 degs.	14.24	6.18	5.09	2.15	1.10	....	....	....	....
2-No. 12 West.	G	70 degs.	8.75	6.40	2.54	6.10	3.75	.95	....	....	....
2-No. 12 West.	14	65 degs.	7.36	5.30	3.10	3.08	1.92	.95	....	....	....

The practical objections to test (as shown in Fig. 48) are that it is laborious, and requires constant adjustment to keep the current at a fixed value; also, around any open there will be 500 volts, and a mistake will injure the voltmeter; and, again, with high potential the operator runs the hazard of a shock. In order to overcome these objections test, Fig. 52 was devised.

This requires a 4-amp. lamp bank, a milli voltmeter reading zero at the

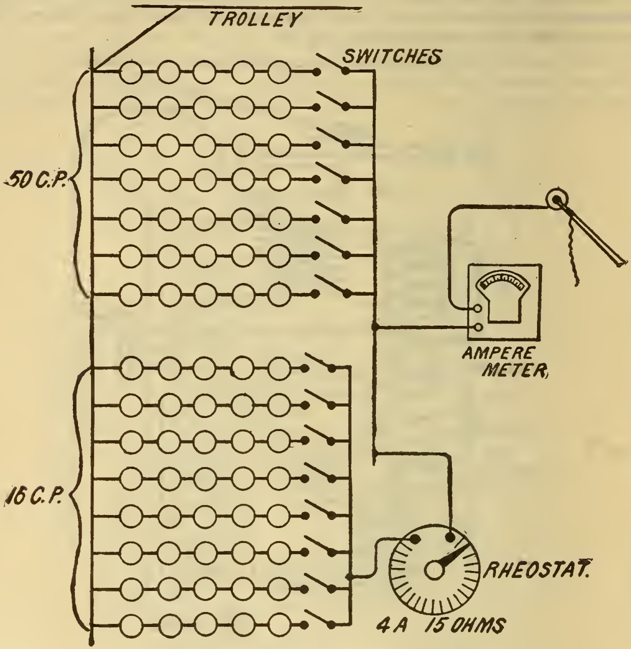


FIG. 48.

center of the scale, and a standard adjusted bridge reading to 20 ohms by $\frac{1}{100}$ ohm divisions, and capable of carrying 4 amps. without any appreciable error. It is convenient to locate the bank on top of the bridge box.

The principle on which this test is made is indicated in Fig. 53. Here the

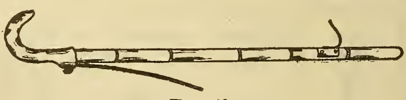


FIG. 49.

bank current splits through ½ ohm balancing arms and, when the current in both branches is equal, the milli voltmeter stands at zero. The variable resistance can be adjusted until this balance is obtained. Then the resistance in the rheostat is equal to the resistance in the car circuit. This method overcomes the variation of potential continually taking place when testing with trolley circuits; for the rise and fall of potential affects both branches equally, and the sensibility of the instrument and not the zero of the instrument is affected. The measuring circuit to ground plate being always connected, there is no danger of the operator on the equipment receiving a shock.

To find opens remove the ground connection from under the brake shoe and

FIG. 50.

FIG. 51.

turn the controller until the bank lights up, which indicates passing an open. To locate low resistance grounds, replace the ground plate, remove the car ground connections and move the controller until the lowest resistance point is found. The connection from this point of the controller leads to ground.

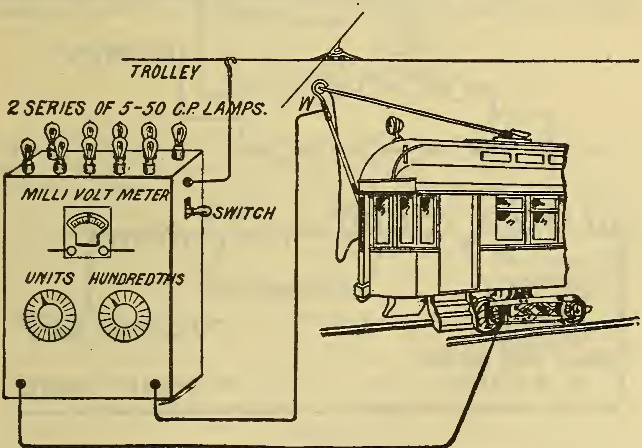


FIG. 52.

A car rheostat varies considerably in resistance especially when used on heavy grades. The G. E. rheostat as a rule falls in resistance with use, while the Westinghouse, Walker and Steel rise in resistance with use. Similar equipments may vary between each other 80% on the resistance steps.

For testing the armature and field resistance when in the equipment, it is best to take two insulated volt test handles and stab the bars on the commutator, which project from under each brush, and read the volts; or a metal brush can be made having in it a pressure point lead like shown in Fig. 54, and substituted for the carbon brush and the resistance of armature thus obtained. For this test there should be a 15-volt scale on the 150-volt voltmeter connected across the test brushes, as the controller contacts and wiring give rise to too large a variable to include them in this resistance test. The fields can be tested by means of plugs

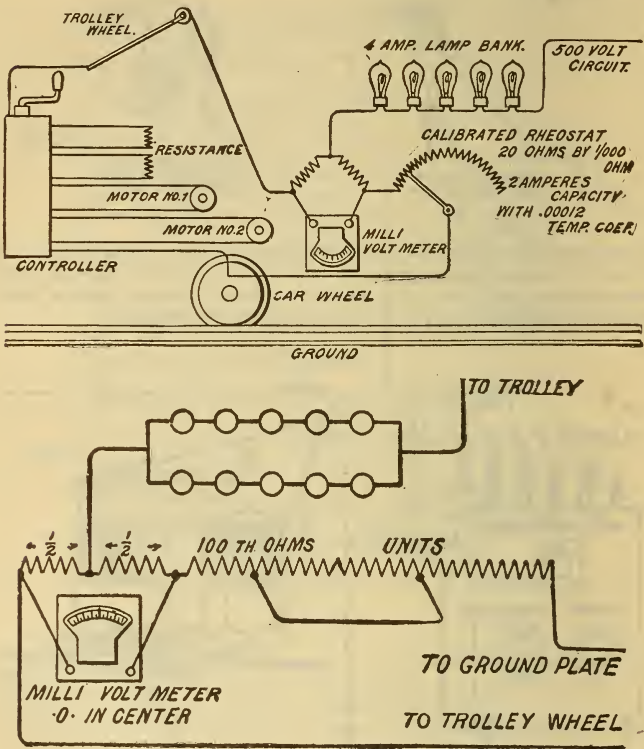


FIG. 53.

shown in Fig. 34, clamped to the field wire leads with the connection shown in Fig. 44. Burnt-out fields are indicated by a lower resistance than the standard set for each type of motor. When cold these fields may appear to be normal and they should be measured when hot if possible.

In order to measure the temperature of a motor by field resistance, it should be borne in mind that the resistance of copper increases .21 of 1% for each degree rise in Fahr. A Westinghouse 12A field measures cold approximately .575 ohms at 60° Fahr. If the motor comes in hot and measures .620 ohms, the temperature can be found by dividing the increase in resistance, .065, by the resistance of field at 60°, .575, which gives 11.3% rise; dividing this again by .21 will give 53.8° Fahr. increase, or 113.8° Fahr. actual temperature.

The armature of this motor measures about .303 ohms at 60; its temperature can be obtained in the same way by resistance measurements. Curves 'aid out for temperature corresponding to hot resistances give the rise direct, and save computation each time. Again this is useful for locating poorly soldered armature leads, which will show high when hot. If the calculated temperature is higher than the temperature as shown by a thermometer placed on the body of the armature and protected from external radiation by waste placed over the bulb, then the armature should be tested for faults.

TEST FOR POWER CONSUMPTION IN STREET RAILWAY EQUIPMENTS.

The power consumption of an electric street car passing over a given route at a specified schedule will vary when any one of a number of conditions are

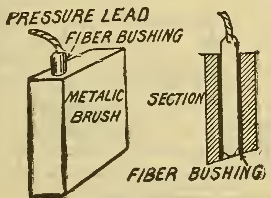


FIG. 54.

changed. Density of traffic (which will vary the number of stops), the location of stops, the loading of the car, condition of track and obstruction of headway, all introduce conditions in the operation of the car affecting the amount of power required to propel it over the route. In comparing the different types of cars among themselves the variables are the motorman, trucks and length and weight of car bodies and method of control. In comparing different sections of tracks the variables are grades, condition of road bed, potential of power delivery and track construction. Tests must be made to determine these variables in order that the result of the different tests on different roadways under the various conditions that arise in practice may be compared. Of course, a number of these variables need be determined only where definite values are to be fixed, but methods for making all the determinations will be given.

The first variable usually determined is the power value of a start. This value varies with the grade, the time allowed for acceleration and the method of motor control. Where a mixed car equipment is used on the road one car is selected, which type represents the average conditions of all the types used. In order to make these determinations a portable integrating wattmeter should be connected so that all the current passes through the series winding, as shown in Fig. 55 and the armature connected between trolley and ground; also in series with the wattmeter is an ammeter, A, through which all the current supplied to the motor passes and the line potential is read on the voltmeter, V.

Switch S should also be connected so that the armature of the wattmeter can be disconnected from the line potential. In order to determine when the car has reached its maximum speed on level track, ammeter readings should be taken when the car is passing over a level stretch of track with the controller on the last notch; the constant current taken under these conditions required by the equipment will be the maximum level run constant. This constant can be determined on different points of the controller where the car can be continuously operated.

For the determination of the power value of a start from the state of rest to maximum speed, the car should be stopped at a marked position on the track where it will have at least 600 ft. clear headway and the reading of the integrating wattmeter taken. The pressure switch which connects the wattmeter armature across the line is now thrown in. The car is started up with regular time between controller points and the rise and fall of the current through the ammeter watched carefully. The instant the current has fallen to the maximum speed value previously determined, open switch *A*, and at the same instant note the point that the car is passing. A number of starts will have to be made from the

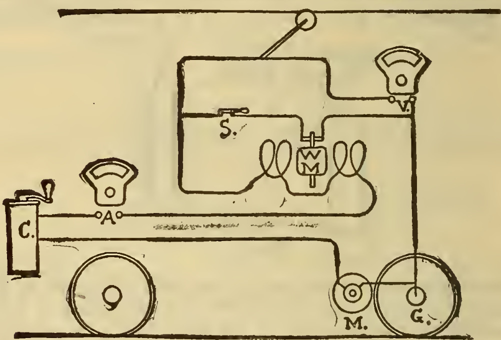


FIG. 55.

same point and the car brought to full speed within the same distance, until the total watts consumed, divided by the number of starts, will give the same constant. Maximum speed constants will have to be determined for the different grades on the road, for different loadings of the car and different points of the controller and curves plotted for these results. These determinations are used in connection with the following tests in order that the power consumption of the cars in practical operation at different times of traffic density may be compared.

Different rates of acceleration can be determined in the same way, and the distance and energy required to get to maximum speed. From these tests, then, the best method of handling the controller can be developed, both for schedule required and economy in power consumption, by making test runs over track sections and varying the method of handling the controller, both in the series multiple and loop positions, for different grades.

To determine the kilowatt consumption per car mile under the practical traffic conditions of a road and the power required by different kinds of car bodies, trucks and equipments, a section of tracks should be selected which represents the average track condition of the system, which should not be less than three miles long. A profile of this section will help to analyze the results, but the following precautions must be taken in getting data from these runs so that the different cars will be comparable as to power consumption. If the wattmeter is read only at fixed intervals of time or distance or when an equal number of watts have been metered, the values apply only for a level track. Where there are several grades in the test section, readings of the wattmeter should be taken at the moment the car reaches the top of the grade, going in both directions over the test track. This will obviate the error introduced by drifting, for an easy running truck over a variably graded track may show a very high economy, with the car passing in one direction. This is due to the fact that the motors are working at full efficiency for a a short time while climbing a short sharp grade, and after reaching the top, the car may drift for a long distance; yet in the return trip the motors will not be worked economically while climbing along moderate grades to reach the top, and have only a short period of rest while drifting down the steep short grade. Also, if the car stops at the end of the test track at a level lower or higher than at the beginning, the complete run to the end and back is the only one that will give comparable values as to power consumption. These points must be borne in mind in arranging the test, so that seemingly contradictory results will not be obtained.

The other data to be obtained on these runs are the times which elapse between the start and finish of the test runs. All stops should be noted, and all stops longer than thirty seconds should be timed. When the car is left running on a particular point of the controller, it should be noted. The maximum current rise and the running current values with the line voltage for both these values should be noted, where specific values are to be determined for a different car equipment; but these variables can be averaged out and a practical average car consumption value per car mile can be obtained if a large number of runs over the same test track for each equipment tested be averaged.

A wattmeter in the station will show higher watt readings per car mile than those shown on a car test, as the readings will be increased by the line drop and ground return losses. These values will vary as the distance from the station increases and with the economy of the distribution system.

Data used for figuring the power consumption of electric cars as usually given, are based on a false assumption, when these data are applied to the car mounting grades, as it is assumed that the car continues to mount the grade at the same speed as it travels on the level. The usual method is to take the current required for the level speed and add to it the energy in current necessary to raise the weight of the total equipment through the elevation attained by mounting the grade in one minute of time—mounted, as grades are in practice, with no resistance in series with the motors, in either a series or parallel combination.

It is evident that the only way more energy can be supplied to the motors with a constant line voltage, is when they drop in speed and reduce their counter e. m. f., so that more current can flow. Consequently, the above assumption will lead to erroneous results, as the car will at all times adjust itself to such a speed as to obtain the maximum energy for mounting any grade when there is no external resistance in series with the motors. This makes the grade determinations of power consumption very important, as they cannot be figured with the degree of accuracy required for power consumption determinations, due to the large number of variables which affect the current flow through the motors; but it is a wise plan to use the above approximate method in figuring the railway feeders as it introduces a factor of safety in railway feeder calculation which is usually neglected.

While the wattmeter gives the operating economy of the equipment as regards the demand on the power station, it does not indicate the best economy of operation with respect to the heating effect on the equipment; and as the depreciation and repairs of motors are largely dependent on the temperatures at which they are operated, the integrating wattmeter is not a criterion of the best method under a varying potential delivery due to feeder and return drops. The reason of this is that the heating effect is a function of the square of the current, whereas the motor heating per car mile will increase a great deal more rapidly than the watts per car mile, when operated under potentials lower than those for which the equipment was designed.

TEST FOR MOTORMAN'S CHARACTERISTICS.

To obtain the motorman's characteristics for running his motors, the maximum ammeter readings have to be taken in connection with wattmeter readings. On starting it is also necessary to take the volts delivered to the equipment, for as the

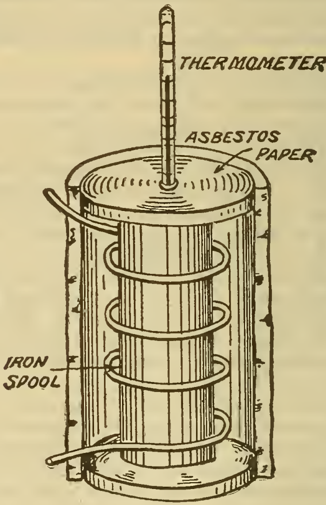


FIG. 56.

volts fall, the efficiency of the equipment falls, and therefore a mile-run on a part of the system distant from the power station will not show the efficiency of a mile-run of the equipment under the same conditions near the power station.

The average motorman's characteristics can be more clearly ascertained by the C^2R effect of the current which results in heating the motors. They can be measured by making a motor calorimeter (Fig. 56) as follows: A wrought iron spool has a hole drilled at the top to receive a thermometer and is filled with mercury; around the spool is wound No. 6 B. & S. copper wire for double motor equipments, and No. 5 B. & S. copper wire for four motor equipments. The main current to the motor is carried through the calorimeter which is insulated to have practically the same rate of radiation as the motor; then the temperatures obtained by the calorimeter correspond to the motorman's efficiency in handling the motors.

ACCELERATION AND BRAKING TEST.

The same connections that are used in the above test are used in testing the efficiency of acceleration, with the addition of the apparatus shown in Fig. 57. This instrument, which is located in the car, consists of a long pendulum, *A*, arranged parallel to the rails, and a pencil carrier, *E*, which is moved over a sheet of paper, *D*, by means of a fine cord belt, *F*, passing over rollers, *C*,*C*,*C*,*C*. The paper may be fed along by hand, clockwork, or may be connected to the car axle by a belt, *B*.

The zero line is made for the pencil carrier when the pendulum, *A*, is hanging plumb. On starting the car the pendulum bob will be deflected and as long as

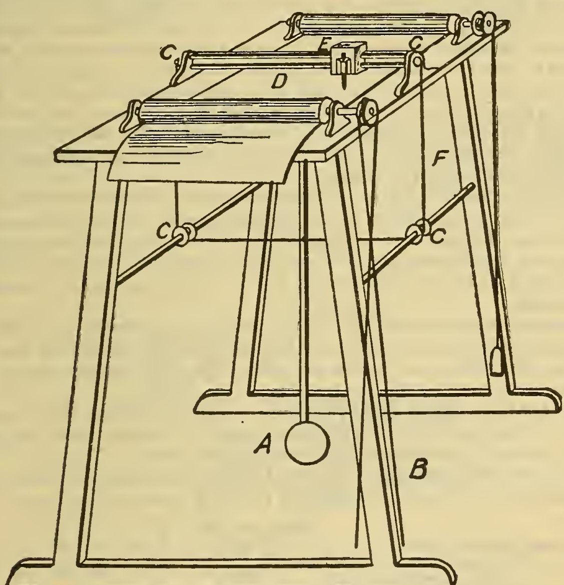


Fig. 57.

the car is accelerating, will not return to the zero line; as soon, however, as it reaches the zero line again, the car has finished its acceleration. The wattmeter is first read before the car is started and again when the pencil carrier returns to zero.

It is convenient to have a switch in the pressure line which can be opened the instant the acceleration has ceased, and the wattmeter is read. To find the distance required for acceleration, if the paper is fed from an axle which is not driven by a motor, its rate of feed can be calculated or calibrated very easily by a few test runs between known distances.

In making a brake test the pencil travels in the direction opposite from zero.

Here the time is noted as soon as the hand leaves zero until it returns again, and if the paper has progressed in a ratio to the movement of the car, this curve will give the relative braking effect of the shoes on the wheels.

Where acceleration is to be determined on grades, the pendulum will draw curves on the paper proportional to the grade over which it passes; in this case, therefore, the zero is to be marked at the instant of applying the brake, and the braking effect refers to this zero and not to the level track zero. The same precautions must be used in acceleration tests.

When an ammeter is placed in series with both motors in an equipment (generally most conveniently done by taking out the fuse and substituting ammeter leads), the ammeter will show a large flow of current when the controller is put on the first point. This rush of current will not reach that which should be shown by dividing the line potential by the equipment resistance, due to the momentary inductance of the motors. As soon as the equipment moves, the current will be found to fall, due to the counter electromotive force of the motor armatures, that is, the armatures are revolving in their fields, and in them is induced a potential which in direction is against the potential of the current operating the motor; this produces a throttling action in effect like that of a resistance in the motor circuits. Due to this the resistance can be cut out of series with the motors as they rise in speed.

The ideal acceleration is one in which a constant current flow would be maintained through the equipment, and the resistance would be cut out as the acceleration increases the counter electromotive force of the motors (until the equipment has reached maximum speed). For methods of approximating these resistances for the different types of equipments and controllers, see under "Equipment Adjustments."

There are three methods that can be used for acceleration tests. One, the stationary current values, the time and total distance; the second, the fixed time between controller points, reading the current and total distance; and the last, fixed distance, current and time variables.

The test track can be marked with eleven numbered stakes 100 ft. apart for 1000 ft.. The track should be practically level. With high speed equipments a 1500 ft. stretch is necessary when the first method is used.

The acceleration tests on an equipment with K_{10} controller and two 12A Westinghouse 30 hp. motors give the following results of current on each step:

Steps:	1	2	3	4	5	6	7	8	9
Equipment up to standard	68	35	26	23	20	68	71	63	52
" with badly proportioned and low rheostat resistance	100	22	27	27	22	120	70	65	60
" with baked fields in motor	120	97	85	84	82	130	100	95	90
Running alone with No. 1 motor	140	110	90	64	50				
" " " No. 2 "	160	130	100	80	82				

showing the location of the bad fields in No. 2 motor. With a stop watch bad fields can be located by first running between fixed points, from 1000 to 2000 ft. apart, with motor No. 1 alone and taking the time elapsed between passing both posts, then going over the route again with No. 2 motor. The time to cover the distance should be the same for both motors if they are both good, or both burnt out (which is rarely the case without the fuses going so as to indicate trouble). This is also a good test to discover whether the fields are properly connected up.

In K type controllers do not use the loop around fields as these loops vary in resistance enough to affect the running times and thus throw suspicion on the fields.

MOTOR TESTS FOR REPAIR SHOPS.

The Prony brake method is sometimes used where the efficiency of the motor is to be determined. A double flanged pulley, as shown in Fig. 58, is belted to the axle shaft, and over it is fitted a short hard wood beam; a brake strap of rope or sheet iron lined with wooden shoes is arranged so that it can be tightened

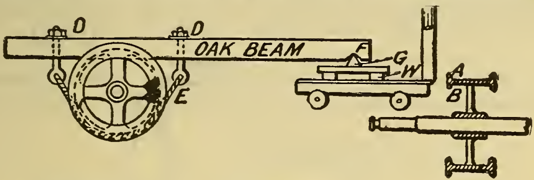


Fig. 58.

or loosened by the nuts, *D D*, At a fixed distance from the center of the axis is a notch, *F*, in the lower side of the lever which rests on a knife edge, as at *G*; this is mounted on the platform of an ordinary weighing scales. This beam should be balanced so that the end of the beam will not rest with weight on the

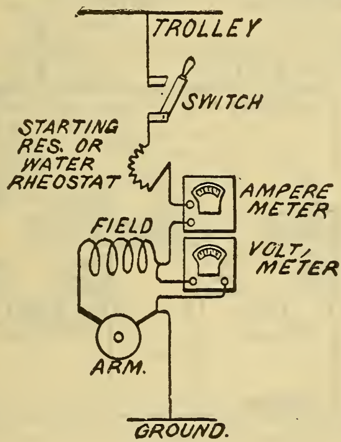


Fig. 59.

platform scales; rubber washers, *W*, are interposed to deaden the vibration from *F* to the scales.

The motor is connected up as shown in diagram, Fig. 59, the voltmeter across the motor and the ammeter in series with it. In addition, a tachometer is required to read the speed of the motor. The water barrel rheostat is best where the voltage varies, so that the test can be made under identical conditions of line potential by varying the rheostat.

After switching on the current and starting the motor, any desired load can be obtained by tightening the nuts and drawing up the eye-bolts, thus increasing the friction between beam and pulley. If the horizontal distance from the center of the pulley to the bearing point of the beam on the scale platform were equal to the radius of the car wheel the pounds indicated upon the scale would be the pull at the periphery of the car wheel for the current passing; if this distance were equal to four times the radius of the car wheel, the scale reading should be

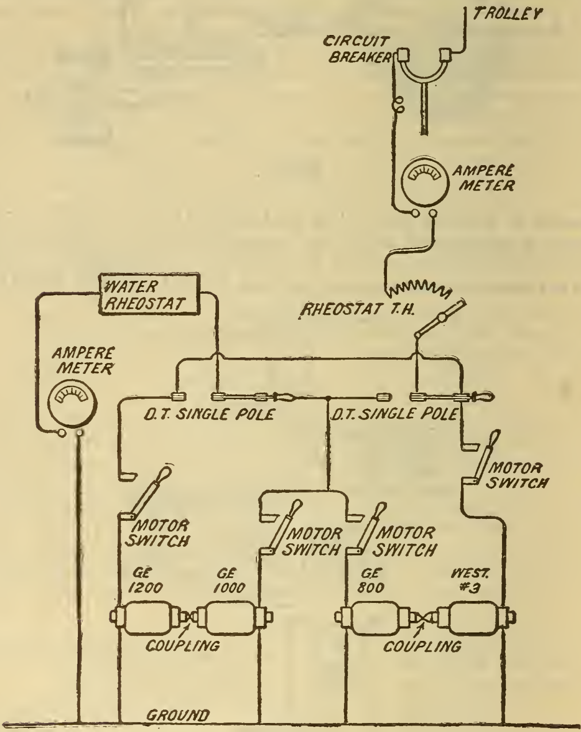


Fig. 60.

multiplied by four to obtain the pull at the car wheel. By placing a tachometer against the end of the axle, a speed reading, usually in revolutions per minute, at any load may also be obtained. To calculate the horse-power developed by the motor for any given amount of current passing, proceed as follows: Multiply by two the radial distance in feet and decimal parts from the center of the pulley to the center of the notch on the beam and this result by 3.1416, which gives the circumference of the sweep of the beam were it free to move; multiply this result by the revolutions per minute, as read from the tachometer, and the result is the speed in feet and decimal parts per minute. Multiply this calculated speed by the pressure the beam exerts against the scale platform, when balanced, and divide the result by 33,000, which gives the horse-power exerted by the motor; and dividing the horse-power exerted by the horse-power supplied (which is obtained by multiplying the amperes and volts together and dividing by 746) gives the efficiency of the motor. In this is included the friction of gearing and axle.

TESTING MOTORS: MOTOR-DYNAMO METHOD.

Here the Prony brake is replaced by another motor. Both motors should be coupled together by a chuck, which will slip over both pinions on the ends of the motor shafts with screws set down between the teeth on both pinions; the

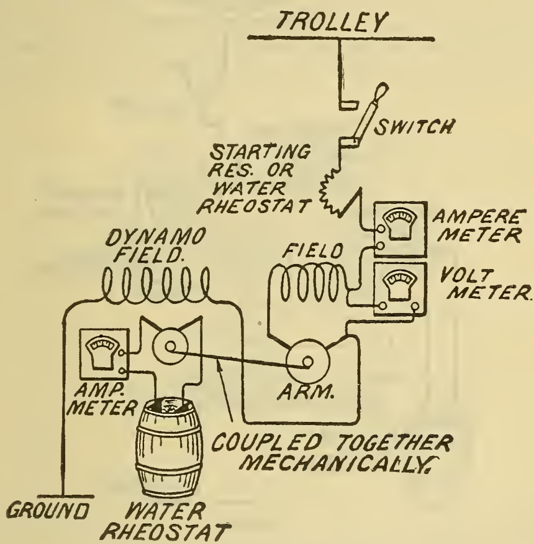


Fig. 61.

motors will then rotate together. Fig. 60 shows a diagram of the connections required for testing two pairs of motors at once. With the switches closed, the Westinghouse 3 and the G. E. 1200 would be operating as motors and the G. E. 800 and the G. E. 1000 would be operating as generators through the water rheostat. This test is used more extensively to determine the insulation resistance of the armature windings and as a running test for armatures rather than to make efficiency measurements.

The usual rule is to run each machine ten minutes as a motor and ten minutes as a dynamo; if no excessive sparking or other faults arise the armature is put in stock for use. The motor fields are best turned upside down, so that the brushes do not interfere with lifting the armature to be tested in and out of its bearings.

The different ways of connecting up the motor are shown in Figs. 61 and 62.

In Fig. 61 the field of the motor running as a dynamo is separately excited; the motor to excite itself as a dynamo has to be run in the opposite direction from that which it runs as a motor, or the field leads should be interchanged.

Dividing the kilowatts output by the kilowatts input gives the total efficiency of the transforming system, including all losses in both motor or dynamo. The efficiency of the motor is greater as a rule when operating as a motor than when operating as a dynamo.

To make detail tests on a motor, the dynamo should supply all the current required by the motor, and the power losses should be compensated for by a second motor, geared or belted to the motor generator so as to run it faster than

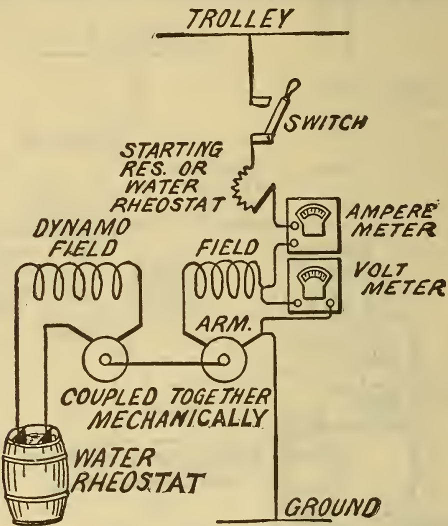


Fig. 62.

at its rated current and speed. A dynamo machine, when running at a given speed, will not produce an e. m. f. as great as that which it will require as a motor under identical conditions.

Fig. 63 shows the diagram of connections employed. A (the dynamo) and B (the motor) have their armatures and fields in series and are connected so both revolve in the same direction.

The necessary increase in speed of A can be approximately calculated if the current, C, and internal resistance of its armature and field, a, are known; then $a\,C$ is the drop in the machine due to the resistance. Let V be the desired volts at the motor terminals; the counter e. m. f. will be equal to $V - aC = E$. Let S be the speed of the machine when running as a motor with V volts and current, C. Since as a motor it generates a counter e. m. f. of E volts and as a generator it produces V volts, then

$$E : V :: S : S'$$

S' being the speed required by this motor-generator so that the motor can operate from the current supplied by the generator to which it is coupled.

Mr. Parham gives the following method of carrying on this test:

A and *B* have their fields and armatures in series, as shown in the diagram, and included in the circuit are a switch, *K*, and a variable resistance, *R*, capable of carrying the machine's full current. *R* exceeds the critical resistance of the machine for the given speed, so that upon closing *K* the dynamo will not generate until part of *R* is cut out. Before starting a test it is well to determine the correct position of the rheostat handle for the dynamo to generate.

On account of the ability of a series machine to pick up rapidly as soon as it begins to generate, it is well to provide belt guards to avoid the annoyance of losing the belt under sudden overloads. A further precaution is to insert a light fuse at the start, and then cut it out when the test is under way. If the motor shaft is arranged to be thrown in by a clutch the start is much smoother. In starting up, the machine is brought up to speed, *K* is closed and *R* is slowly worked

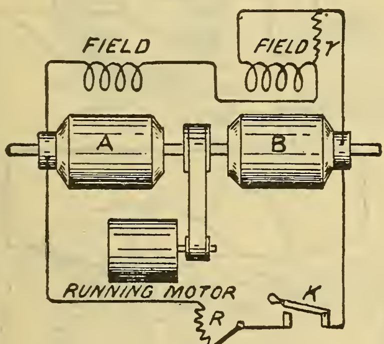


FIG. 63.

out, at the same time *B*'s field is weakened by means of the shunt, *r*, shown in Fig. 63. As soon as the ammeter shows *A* to be generating, *R* must be very carefully handled to avoid precipitating a heavy overload and throwing the belt. *A* will refuse to generate until a certain amount of *R* has been cut out, and will then pick up very rapidly. It is absolutely necessary that means be provided for weakening the motor field, otherwise since the same current must pass through both machines, and since they run at the same speed, the counter e. m. f. of *B* will be the same as the e. m. f. of *A* and a load cannot be worked on. The shunt affords the same regulation as obtains on a car, but has a different relation, in that on a car its value is constant and the speed is variable, while in this test the shunt is variable and the speed constant.

A's current passing through *B* runs it as a motor, and helps to turn the system, thus lessening the demand on the supplier, which then supplies only energy enough to cover the losses, which may amount to from 25 to 35 per cent of the motor's output. After running *A* for a stated time as a dynamo it is changed over and run as a motor. This change is most rapidly effected by using a crossed belt to reverse the direction of rotation; it is then only necessary to move the shunt from B to A.

To separate the different motor losses both motors are run by the operating motor, first free with brushes out and no fields. The reading of an ammeter and voltmeter across the operating motor terminals will give the electrical losses in the operating motor, and the friction and air resistance losses of all the machines. Running the operating motor free with belt off will give some of the losses which should be subtracted from the total input of the operating motor.

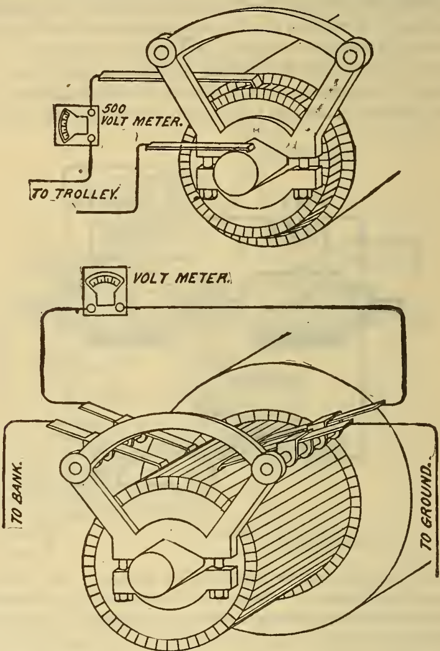


FIG. 64.

To determine more nearly the true friction losses of the motors (the belt loss is still included in the motor friction) care should be taken that the two motors under test are properly aligned with no undue friction from coupling the shafts. Put in the brushes on both motors and read power input, and the difference is the brush friction, which should be divided by two to find the brush friction on one motor.

If the field is excited with different currents independently, and the power required for each degree of excitation is plotted between power taken and excitation current, the core losses at different outputs will be obtained. If a voltmeter is placed across the brushes and the voltage is read for each change in excitation a characteristic curve can be plotted between excitation and open circuit voltage developed at the armature; the set can then be run as a dynamo-motor combination up to overload, the auxiliary motor supplying losses, with a constant current flowing through the system.

Another important point is to have the auxiliary motor calibrated so that from the current input the actual power output will be known, as the efficiency and losses in the auxiliary motor are not proportional to the current changes. This motor should be calibrated with the Prony brake as shown in "Motor Tests," so that a curve of actual output in horse-power will be known from the input in watts.

ARMATURE TESTING.

The armature may have the following faults, which can be located by testing: An open lead from the commutator to armature coil; an open armature coil; bars on commutator short-circuited; coils on armature short-circuited; ground on commutator; grounds in armature.

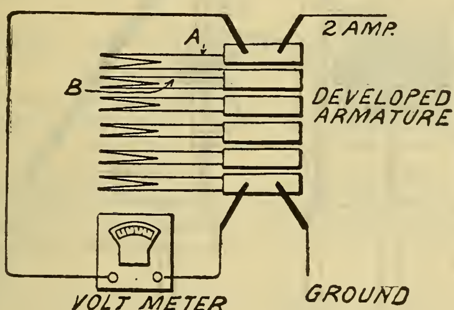


Fig. 65.

Fig. 64 show a contact bracket rig which slips over the armature shaft and can be revolved so that the different bars can be tested; besides this rig the test requires a low reading voltmeter, reading about 1.2 volts full scale, and two amperes from a test bank, which is all the current necessary. If the brushes on the test rig are so located that four commutator bars are between these brushes, the best average conditions for testing the different railway armatures in use are secured. The current is carried through two brushes and the other two take the drop to the voltmeter.

In case of open lead at *A* (Fig. 65) the bank will go out and the current brush will flash when passing to that commutator bar, but it will also be seen that the circuit is completed to ground through the low reading voltmeter so that armatures tested for broken leads to commutator should be tested around the commutator by the lamp bank only first. Then the pressure brushes are lowered and the armature is again slowly revolved and the deflection on the voltmeter watched.

If there is a break in the armature winding, as at *A*, the drop on the voltmeter will increase greatly beyond the normal drop for four bars, for the reason that all the test current has to follow from one brush to the other through the windings of the armature external to the brushes.

The voltmeter will fall again to normal readings when the bar connected to the broken coil passes beyond the test brushes. The bar can be located in this way and marked.

A short circuit between two commutator bars or windings will show a lower reading than normal when the commutator bars to which the windings are connected are between the test brushes, and can be located when passing from under

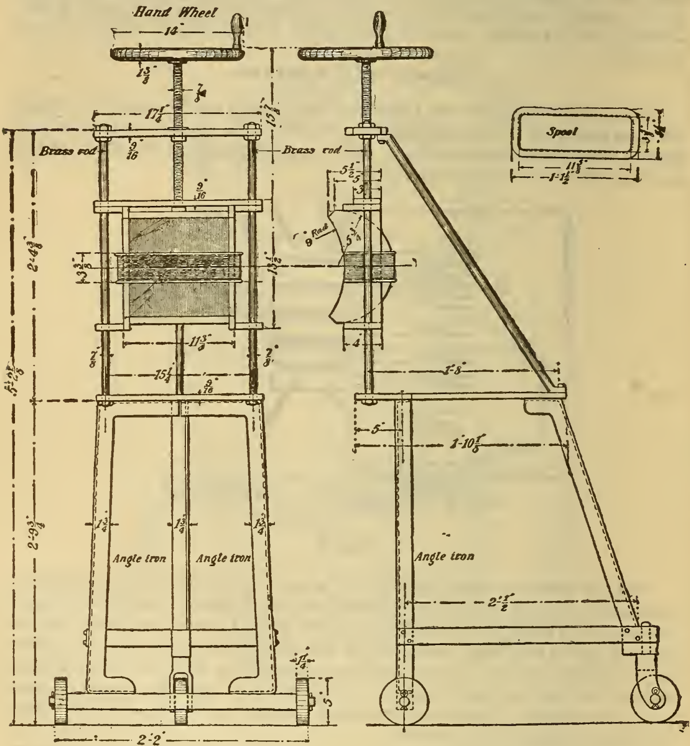


FIG. 66.

the test brushes by the voltmeter reading jumping back to normal again. To determine whether the short is between the bars or the windings, the adjacent bars should be short-circuited by a copper bridging piece, when the defective part of the armature is between the brushes. If this changes considerably the reading on the meter, the short between bars is in the armature. If no change is made the short is in the commutator. For these two tests see next test, which is the most expeditious and searching for shorts in armatures.

For the location of grounds the connections, as shown in Fig. 65, are changed by carrying the current through the armature and then to the ground with a 500-volt voltmeter in series. A green armature should not measure less than 75,000 ohms (See Insulation Test by Voltmeter Method), and a baked armature should be over 1½ million ohms, or 1½ megohms. If the insulation rises on the application of the testing current it indicates the presence of moisture, while if it falls, a leak through a charred insulation is probably present. If the voltmeter shows nearly normal volts then the ground can be located in the following way:

Pass the bank current through the commutator to the shaft and also connect across these points a voltmeter reading the drop between the commutator and shaft; carry the contact and voltmeter contacts slowly around the commutator and watch the voltmeter drop, when this has reached its lowest point, and rises in volts again then the commutator bar connected to the grounded coil is located. Several grounds may exist, and can be picked out in this way by following up each one separately.

INDUCTION METHOD OF TESTING SHORTS ON THE ARMATURE.

For this apparatus working drawings are given in Fig. 66, which shows a framework made of angle iron mounted on three rollers. The testing transformer is made of laminated iron about $\frac{1}{32}$ in. thick and of the shape and size shown in Fig. 66; this is adapted to test G. E. 800-1000-1200 and No. 57, and Westinghouse No, 3 and No. 12. The magnetizing coil is made as shown in Fig. 66, and wound with 1210 turns of No. 13 B. & S., D. C. C. wire. The curved face of this transformer is adjusted by a hand wheel and screw so that it can be shoved up against the armature before the latter is removed from the winding bench.

The body of the armature completes the magnetic circuit of the transformer; the armature is then rotated by hand in this field. If any two windings are short-circuited and are within the influence of this varying magnetism, a local induction circuit is created which causes a vibrating magnetic flux in the teeth of the armature included in the short circuit; this is discovered by passing a thin strip of iron around the armature, which when over a short-circuited coil will vibrate in unison with the alternating current supplied the transformer. There will be two such points in the armature at a quarter from each other when two adjacent armature coils are short-circuited, but at four points when the short is between the commutator bars in a four pole cross-connected armature.

The current for this testing device may be obtained from a railway motor (an old style one will do), changed over for this purpose. Two slip rings should be secured to and insulated from the shaft, and connected to the windings of the armature. The connections in a two-pole motor should be located one-quarter of the circumference of the armature from each other and in a four-pole motor, one-eighth of the circumference apart. The motor should then be wound with a shunt field of fine wire. With a two-pole motor a speed of 1400 r. p. m. gives a good frequency to detect these crosses.

The armature room should be wired for this current over the winding benches, and flexible cords with attaching sockets located at points convenient for connecting to the testing device. While on the winding bench an armature can be tested by this method in less than one minute.

FIELD TESTS.

In fields the fault most generally looked for is a short circuit between the layers. This may be caused by charred insulation from overheating, or by a breakdown in the insulation between the windings.

A field coil should never measure more than 5 per cent under its standard resistance; annealing will account for this difference in some copper wire. A field may be low for the reason that turns are shy or have been cut out in repairs, both of which are bad practices, and should not be used where the best service from the armature is desired.

The most treacherous defect in the whole equipment is a baked field. These will test O. K. when cold, but when hot will show the defect; this is due to the expansion by heat; the convolutions are brought into more intimate contact and turns shorted out.

For testing a cold equipment the connections are shown on page 31. While the current passes through the field, if mechanical pressure can be brought to bear on the cover or spool face so as to bring the wire in the field windings into close contact, and the reading on the voltmeter changes, this will indicate at once that the field is baked.

When testing separate field spools that have been used, always stand on them, when, if they are baked, they will show change in resistance due to shorts set up in the coil due to pressure.

The method of testing for field grounds in the equipment, is already given in Equipment Test pages 50 and 51.

CONTROLLER TEST.

The test on the controller consists of locating grounds and shorts. A ground can be located after first disconnecting the controller from the equipment and then testing for grounds the same as in the case of the equipment ground test.

When the controller is disconnected from the equipment each clip has to be tested separately for grounds and different portions of the controller cylinder to see that the contact rings are not connected with each other. The test can be carried out by a magneto or a series of five lamps or a Weston volt meter in series between the line and the clips, having the other side of the line connected to the controller back. In some types of controllers the ground is permanently connected to this back frame of iron, which connection should be removed before attempting to locate other grounds.

RHEOSTAT TESTS.

Testing the rheostat for resistance is done in exactly the same way as that shown for fields. The resistance is measured on each step by connecting the voltmeter leads to the terminals of each step when a known current is flowing through the whole rheostat.

For locating an open, connect the rheostat between the lamp bank and ground. Then take a piece of wire and bridge or jump around the open, reducing the span of the bridge until the break is located between the bridging wire.

Grounds on the resistance can be discovered in the same way as given for controller test.

TEST ON RAILS.

According to D. K. Clark the usual tests for steel tramway rails are:—

Breaking stress (tensile), 37 to 43 tons per square inch.

Elongation in length of 8 inches, at least 15 per cent.

Contraction of sectional area, at least 30 per cent.

A piece of rail 5 feet long, on supports 3 feet apart, to resist a blow from weight of one ton falling on center from given height without causing more than 1 inch deflection; a second blow from another given height without exhibiting sign of fracture. The height of drop of first and second blow are determined by the following table.

Weight of Rail per yard.	Height of First Fall in feet.	Height of Second Fall in feet.
60 to 70	6	15
70 " 80	7	17½
80 " 90	8	20
90 " 100	9	22½

POLE TESTING.

The method usually given to test a pole is to set it the proper depth in the ground, apply a tackle to the top and draw it up with a given tension, noting the deflection. The tension is usually applied at an angle from the ground, and is borne partly by the pole longitudinally and partly by the spring of the

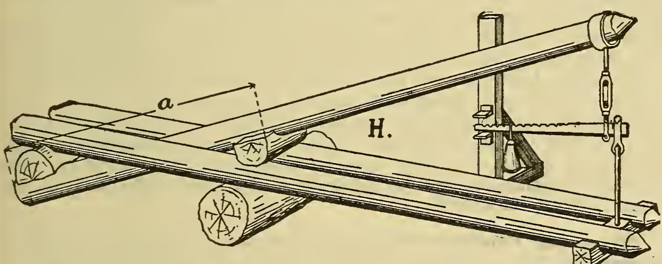


Fig. 68.

pole. The ratio of the two depends on the angle of application. Any yielding in foundation is liable to be charged to elasticity. If the pole is planted in cement, several days should be allowed the latter to set before the test, which makes a rather lengthy affair. I have found that the following will give all the practical results necessary and can be readily constructed and calibrated on the spot. See Fig. 68. For this testing rig two of the largest and most symmetrical poles are selected; they are then laid by the side of each other and separated far enough apart to allow any of the poles to be tested to lie between them. They are braced together at two points, the distance a, from the bottom of the foot brace to the top of the head brace, to be the depth of setting to be employed for the pole. Sufficient area to these braces should be given at H so that the strain applied will not crush the fiber of the pole under test. A 12-in. turnbuckle, and a 1:20 steelyard, with a 100-lb. weight, completes the outfit.

One arrangement can be made as above. The weight on the steelyard is fixed, and, after the bridle is put over the pole, the turnbuckle is tightened until the steelyard is balanced. When the specified tension is applied, the deflection of the pole is measured by a mark on a board opposite the pole under test.

This deflection is composed of the yield of the braces and the flexibility of the crib, but the pole on returning will show the permanent deflection which will be the difference before and after strain.

Iron poles can be tested by the same method by substituting an iron pole for the wood, and the steelyard should be provided with a set of weights, so as to reach a 2,000-lb. strain, where extra heavy poles are to be tested.

CEMENT TESTING.

A rough way to test the quality of cement is to take two batches of about a handful each, mixed with as little water as possible, and make them into cakes. Put one of these cakes in water and the other in air. If the cake in the air dries with a light color without any particularly well defined cracks, and the water cake sets with a darker color and without cracks the cement is probably good. If the cement cracks badly in setting, or if it becomes contorted (sometimes called blowing), it is poor and should be rejected.

Kidder gives another simple test for the soundness of cement. This is to place some cement mortar in a glass tube (a swelled lamp chimney is excellent for this purpose) and pour water on the top. If the tube breaks the cement is unfit for use in damp places. Any natural cements that give satisfactory results with these simple tests will answer for making mortar for any ordinary building construction. A good cement will not expand, contract, check or crack when setting. Where great strength is required in the mortar it is better to use Portland cement, but if for any reason Portland cement cannot be obtained or its price prohibits its use, the strength of the natural cement should be carefully tested in the manner described. Clear Rosendale cement one week old in water should have a tensile strength per square inch of at least 60 lbs., and the best brands should average 100 lbs.

Measuring Fineness: "The degree of fineness of a cement is determined by measuring the per cent which will not pass through sieves of a certain number of meshes per square inch." A cement that will pass through a sieve of 2500 meshes (No. 35 wire gage) with only 5 to 10 per cent residue is sufficiently fine for any building construction.

TEST FOR OVERHEAD LINE INSULATION.

Testing for overhead line insulation is best done by clamping to the trolley pole, near the harp, two blocks of fiber to which are attached two strips of phosphor bronze. The latter should project beyond the trolley wheel, far enough to come in contact with the span wire, and as the car passes along these flexible strips should make contact with the span wire. Then connect a 500-volt voltmeter between a lead from the strips and the ground so that only such potential as can leak through the trolley insulator can deflect the voltmeter. If the voltmeter is calibrated in insulation resistance in a way similar to that described in the section on testing equipment, the resistance can be read in megohms as the car passes slowly along, striking each span wire.

HIGH TENSION INSULATOR TESTING.

As the potential on a line increases, the tendency to loss by leakage increases in a ratio varying nearly as the square of the potential. This is the case with bare conductors, but when insulated conductors are used losses by leakage increase less rapidly, on account of the combined effect of the two insulations. The insulation afforded by an insulator varies with the moisture in the air, dust, temperature, and other climatic conditions.

If the material forming the body of the insulator is a good insulator, the loss on each insulator is a matter of surface leakage. In the design of insulators and the securing of the conductors to the insulator, the subject of areas of leakage is not usually given proper attention. The external surface of an insulator once determined, the value of this surface as an insulator can be computed approximately by ascertaining what is the cross-section and length of a film of moisture which could be deposited thereon. The linear distance from the point of connection with the conductor to the point of contact with supporting pin multiplied by the mean circumference of this path, will give a comparative value for insulators of the same material which will vary as their insulating qualities. The insulating values of these leakage surfaces vary with the exposure to the weather. The external surface of a bell has in damp weather no appreciable insulating value, but the petticoats provided underneath the bell maintain the insulation.

It is hardly possible to pierce insulators made of glass by increasing the potential, as they will withstand a potential which will flash over the external surfaces and arc between the pin and conductor before the glass is actually pierced. The glass surface on being exposed to rain is serrated and grooved, due to the solvent action of rain water on silica, and these roughened surfaces allow the lodgment of dust and soot, which forms a partial conducting medium, and reduces greatly the effective insulation. A test made on forty glass insulators, representing a mile of line, after being dipped in water once and a little dirt removed, gave a resistance of 23,220 ohms per mile. After being dipped four times this resistance increased to 56,400 ohms. With new insulators and pins 66,600 ohms per mile was found.

With high tension currents, particles of moisture are repelled from the conductor electrostatically, and foggy weather, for this reason, does not bring down the insulation of the line as much as on telegraph and low potential lines. When a leak over the surface of an insulator is established, the current flowing over this leak raises the temperature of the insulator and dries up the conductor moisture.

Power transmission lines require the stringing of wires of considerable weight per foot, and the fragility of glass has made it an uncertain mechanical support for these conductors when under tension. It is very important that the conductor should never touch the cross-arm or pin, as the leak will probably burn up the pole if of wood, and if of iron, it will cripple the conductor system. Porcelain, when used for the body of the insulator, possesses more mechanical strength and the surface of porcelain when good, weathers exposure without deterioration. In the clay from which these insulators are made, a large proportion of American kaolin should be avoided where the insulators are to be used for high tension work, as these clays are too refractory to completely coalesce or vitrify when fired, and consequently they lack homogeneity, an essential quality in a high potential insulator.

[illegible] porous insulators can be easily detected by applying aniline ink to a fractured surface. If porous, this ink will be absorbed into the porcelain, but if thoroughly vitrified, the ink can be washed off without leaving any stain. This test should be tried on the thicker portions of the body of the insulator, as they may not have been vitrified, while the thinner portions reach sufficiently high temperatures to be vitrified.

The specific insulation of porcelain is less than that of glass, and being opaque, it affords a good harbor for the nests of insects inside the insulator; but on account of its superior mechanical properties, it is used on nearly all the transmission lines in America employing high potential.

Insulators for high tension lines should be tested individually at at least four times the electrical pressure under which they are to be used. This will probably give a factor of safety of 16.

The method of testing generally adopted is to insert the insulator head down in a shallow pan, into which is poured sufficient solution of bicarbonate of soda and water to reach above the groove for the tie wire. The same solution is poured in the hole for the pin, and in this is inserted a metallic wire which forms one terminal of the high potential circuit, the other being connected to the pan on which the insulator rests. The testing potential applied should be of the same character as that to be used on the transmission lines. A metallic conductor connected on the outside of the insulator, in the same manner as used in the transmission line, and the insulator screwed down with a metallic pin, reduces the area of contact, so that the insulator will stand a much higher potential than in the test given above. When in actual practice this conductor is supported in the rain on this insulator, the area of contacts will be much greater than in the dry test. The insulator should be submitted to the testing potential for some time, as for a few moments it may stand a much higher potential; but it is under a stress which reduces its insulating values, and if applied long enough may break down the insulator. Ten minutes should certainly determine whether this fatigue would reach the rupturing point. It is hardly advisable to place any insulators on a high potential line without first testing them individually, for the reason that in the formation of the insulator in the mould, the clay has to be moulded under a uniform pressure. If this pressure is not distributed throughout the clay while in the mould, it will cause the clay to be of unequal density throughout the body of the insulator, which will result in unequal shrinkages while firing. These differences will cause small fissures through the body of the insulator, and this inequality will lead to a breaking down under the potential test. This condition is not evident from external inspection. The final glaze on an insulator should be entirely burnt into the porcelain itself. If too much glaze is put on it is worse than none at all, as this glaze has all the characteristics of a glass surface.

When an insulator breaks down under a high potential, it is actually punctured by the current, which usually pierces between the pin and the external surface of the insulator. Under 60,000 volts, a poor insulator will explode with some violence.

The open double petticoat insulator was found to dry more rapidly than the closed single petticoat insulator, but during actual rainfall the insulation lost by the double petticoat form is greater and more rapid than that of the single form. In order to break the conducting film of moisture on the surface of an insulator, several methods are used; one is to have an internal groove in which oil is poured. This interrupts the continuity of the moisture film and improves the insulation. Lining the top of the petticoat with paraffin has also been tried with partial success.

Another feature of design of these insulators for high tension work is to make them helmet shape, the rim of the helmet being over the cross-arm, so that water dropping from this insulator will not fall directly on the cross-arm, and spatter moisture underneath the insulator. The greatest leak on transmission lines occurs during fogs, and the greater the change in temperature, under foggy conditions, the greater the leak. The insulation of a line rises as soon as rain begins to fall.

The method of securing high tension lines to their insulators is to provide a groove in the top of the insulator, in which the conductor rests. The conductor is held in place by a tie-wire, the object of this wire being to hold the conductor in the groove, and yet allow of contraction and expansion of the conductor, without bringing additional strains on the line.

Pins.—Wooden pins are as a rule preferred for supporting these insulators. They should be made from split locust and their values as an insulator are increased by being boiled in paraffin.

Some tests on the leakage of cross-arms, made in New York City, are given, but in the test the length and dimension and method of test of the cross-arm are not stated; consequently, the results are only comparable among themselves.

	Ohms.
All four surfaces wet with sponge	3,120
Soaked one day, left to dry one day, and then wet	2,680
Painted three years before test	6,150
Same washed	9,166
Very dry	11,000 to 330,000
Newly painted	7,214
Unpainted for many years	4,300
Same after being well washed	13,653
Same after being well dried	80,000
Arms and pins together (wet)	3,686

POWER STATION TESTING.

It is important to determine the economy under which a station operates under the various loads, management of boilers and engines, and the loading of different units. Such data are essential in order to determine how to best operate the plant for maximum efficiency.

Coal.—The weight of coal that is burnt under the boilers can be readily determined, and when only a temporary test is to be made, a platform scale large enough to hold a wheelbarrow, can be used, Fig. 69. The scale is generally set so that an even number of pounds is weighed each time—either adding or taking off coal, until the scale balances. The coal handler should make a record each time he weighs, and if the coal is to be used moistened, it should be weighed before wetting.

For continuous records of station operation, a number of methods are used. Fig. 70 shows one method of supporting a hopper where the coal is stored above the boilers in bins. The hopper is filled by opening the chute, and when nearly balanced, the coal can be throttled until a perfect balance is obtained. The bottom part of the weighing hopper can then be opened, and the coal delivered on the boiler room floor, convenient to the boilers. It is also suggested to have an electrical contact on the top of the arm of the weighing device, so that each weighing can be recorded on a dial magnetically.

Firing.—Before starting a boiler test, all coal should be cleaned up from the floor around the boiler, so that only the weighed coal will be fired. In making comparative boiler tests, the coal for each boiler should be kept separate. The proper method of firing a boiler depends upon the coal, the furnace, the grate and the draught. An expert will change his methods to suit different steam demands on the boiler.

There are three distinct methods in hand firing: (1) Spreading, which is the common method, where the coal is scattered evenly over the whole surface of the grate, commencing at the bridge and spreading toward the door. (2) Alternate firing, in which the charge of coal is laid along one-half of the grate at a time, from the bridge to the door, each side alternately; with a double door furnace, this is usually the method used. (3) Coke firing, which is more specially applicable to bituminous coal, here the charge of coal is first thrown on the dead plate or front part of the grate, where the volatile matter is burned out and the coke coal gradually pushed back to the bridge, where it is completely

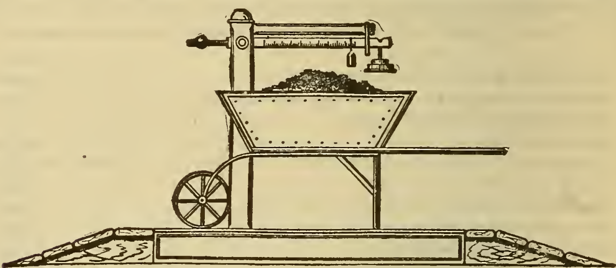


FIG. 69.—HAND COAL WEIGHING.

burned. The steaming advantages of the different methods of firing can only be determined by their application to individual cases.

In regard to the wetting of the coal before firing, this has advantages in some few cases of slow burning furnaces. The action of the excessive water in the coal is to decompose into hydrogen and oxygen in the intense heat of the combustion of the coal, which gases combine again to form water in the cooler parts of the furnace; in combining they raise the temperature of the gas passing through the furnace. The effect is to transfer the active heating of the gases from the furnace fire to other portions of the furnace whose normal temperature is lower. The energy required to raise this additional water to the temperature of the gas leaving the boiler will be lost, and through this range the capacity of water for heat is great.

In the case of wet coal, the temperature of the gases issuing from the boiler may be reduced over the dry coal, but the actual number of thermal units escaping up the chimney may be increased. Water used under the grate to wet the ashes is evaporated by their heat, and the heat radiating downward through the grate bars; this steam passes through the grate up with the draft and reduces the intensity of the heat of the glow fire, and most of the energy used to raise the water to steam when used this way would otherwise be wasted. Ashes should not be wet if they are to be weighed.

Combustion.—Coal in burning combines with the oxygen of the draft, giving up its carbon; first, to form carbonic oxide, CO, and then further combining with oxygen to form CO_2, or carbonic acid, the presence of which indicates complete combustion. Insufficient air supply or incomplete combustion of the coal will change the ratio of carbonic oxide to carbonic acid in the gas issuing from the boiler. The carbonic oxide in uniting with oxygen will give up one-third more energy than if passed out as carbonic oxide. The condition of combustion is indicated by the percentage of carbonic oxide that exists in the gas leaving the furnace. There is an instrument made called a composimeter,

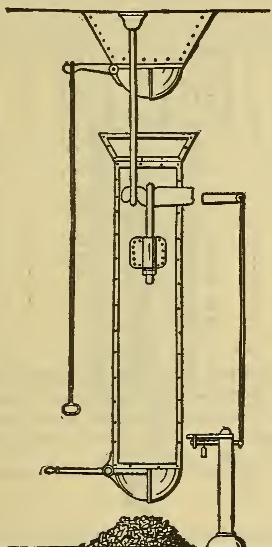


FIG. 70.—AUTOMATIC COAL WEIGHING.

which indicates and records continuously the percentage of carbonic oxide, or CO, in the chimney gas, and indicates the condition of combustion. This is connected directly to the up-take of chimney, and the indicator can be located at any convenient place for the firemen's inspection. The above is only strictly true for anthracite coal; bituminous coal increases in smoke as the draught is increased, or the temperature of fire falls

Each pound of coal requires 21.3 lbs. of air for complete combustion, or at 60 degs. Fahr., 280 cubic feet of air. In coal the carbon, hydrogen and oxygen are the heating elements, and water, nitrogen and ash the waste. For the analysis of some of the American anthracite coals, see under Fuels. Where only an approximate determination of the heating capacity of coal is required, it can be figured from its analysis where the percentage of free carbon in the coal is known.

Example: Take Lehigh anthracite coal which contains 3.7 per cent moisture. 6.3 per cent ash, 84.6 per cent carbon, and 5.4 per cent volatile matter. Deducting moisture and ash, which make a total of 10 per cent, from the 100 per cent, gives 90 per cent; fixed carbon is 84.6 per cent, which gives the fixed carbon ratio of the coal $\frac{84.6}{90}$, which equals 94 per cent.

The table below gives for this ratio 15,120 B. T. U. Ten per cent of this is ash

APPROXIMATE HEATING VALUE OF COALS.

Percentage fixed carbon in coal, dry and free from ash.	Heating value B. T. U. per lb. combustible.	Equivalent evaporation from and at 212° per lb. combustible.	Percentage fixed carbon in coal, dry and free from ash.	Heating value B. T. U. per lb. combustible.	Equivalent evaporation from and at 212° per lb. combustible.
100	14,500	15.00	68	15,480	16.03
97	14,760	15.28	63	15,120	15.65
94	15,120	15.65	60	14,580	15.09
90	15,480	16.03	57	14,040	14 53
87	15,660	16.21	54	13,320	13.79
80	15,840	16.40	51	12,600	13.04
72	15,660	16.21	50	12,240	12.67

and moisture, having no heating value, and consequently the coal would only have 90 per cent of this value, which would be 13,608; as it takes 966 B. T. U. to evaporate one pound of water from and at 212 degs. Fahr., at the pressure of the air, the evaporative efficiency of this coal, if used with perfect combustion and a perfect boiler, would be $\frac{13,608}{966}$, which would be 14.08 pounds of steam at 212 degs. Fahr.

Ashes.—There is always considerable difference between the weighed ashes and the ash found by analysis of coal, caused by unconsumed carbon being carried away with the ash and clinker, and the ash will absorb considerable moisture on being exposed to the air. In analysis, care is taken to prevent any absorption of the moisture by the ash. In temporary tests ashes can be weighed in the same way as provided for coal. Where continuous records are kept the ashes are generally weighed as they are hauled away for disposal. The weight of coal supplied to the grate in a given time, divided into the weight of ash taken from under the grate, will be the commercial percentage of ash, which will vary with different coals, and will be affected by the skill in handling the fire. The importance in knowing the percentage of ash in the different coals used has a bearing on its steaming values, as the wasted ash costs as much as the consumed carbon. It is not always true that the coal that gives the least ash has the highest evaporative efficiency, as bituminous coals are very low in ash, yet may waste their carbon in smoke.

Water.—The amount of water entering the boiler is a third quantity which has to be known in the boiler room, in order to determine the efficiency of steam production. Each boiler should be provided with a water meter attached to the feed pipe near its entrance to the boiler, and it should be so connected to the piping system with flange couplings, valves and a by-pass that it can be readily removed for recalibration. The temperature of the feed water should be known, and this is readily determined by means of a feed water thermometer, (Fig 71). The form made for this purpose can be screwed to a Y connection in contact with the water in its passage to the boiler. These thermometers are graduated from 60 degs. to 260 degs., where feed water heater is used, and from 100 degs. to 400 degs. where an economizer is used.

The heat units that are added to the feed water before its introduction to the boiler above the normal temperature of the water should be deducted from the total units required to evaporate the water into steam at the pressure used. For

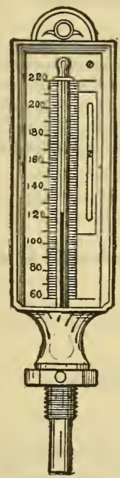


FIG. 71.—FEED WATER THERMOMETER.

this allowance see Table of Properties of Saturated Steam, giving the thermal units in a pound of water at different temperatures, and the thermal units given up by coal combustion will be the difference between those in the feed water and those of the steam issuing from the boiler. The temperature of the draught of the up-take in the chimney, which can be measured by a draught thermometer reading up to 700 Fahr., is useful information in order to determine the management of the dampers and drafts, especially where the forced fire is used for any period of the station load, and also indicates which method of firing gives the best results.

Losses.—Having arranged the above apparatus, the losses which will occur in this utilization of coal in the form of steam are as follows:

First.—Heating draught air to temperature of up-take. As it takes 21.3 pounds dry air at 60 degs. Fahr. to burn one pound of coal, and, assuming the temperature of up-take in the chimney as 560 degs., and each pound of air requires .238 B. T. U. to raise it one degree; then as the air is raised 500 degs. Fahr. the heat units lost per pound of coal are: 21.3 × .238 × 500 = 2,534.

Second—If the relative humidity of the air is 60 per cent., then there will be .007 lb. of moisture in each lb. of air, which is delivered to the chimney up-take, at an elevation of temperature of 500 degs. Fahr. As it takes .48 B. T. U., per pound of moisture for each degree, then the heat required for the moisture in 21.3 lbs. of dry air will be: 21.3 × .007 × .48 × 500 = 36.

Third—The weight of the moisture in the pound of coal is taken at .029 lb., and is first heated from 60 degs. Fahr. to 212 degs. Fahr., = 4.4. As it takes 966 B. T. U. per pound of water to change from water at a temperature of 212 degs. Fahr., to steam at the same temperature, the .029 lb. of water will require .029 × 966 = 28.

Fourth—.029 lb. of steam heated from 212 degs. Fahr. to 560 degs. Fahr., will be .029 × 348 × .48 = 4.8.

For properties of saturated steam see pages 19 and 20.

There is in the ash .02 lb. combustible carbon wasted, which has a value of 14,544 B. T. U. per lb., and which will give in wasted energy, 290.9 B. T. U.

In the draught .0237 lb. C burned to CO, which by incomplete combustion will be .0237 x (14,544—4,451) = 290 B. T. U. The rest will be radiation and unaccountable difference, and the total losses assembled in this way, with coal, having 14,245 B. T. U., are:—

	B. T. U.	Total per cent of B. T. U.
Heating, draught and moisture in draught to temperature of up-take 560 degs.	2,570.0	18.04
Heating water in coal	37.2	.26
Heating water formed by combination of hydrogen in coal	97.2	.68
Loss by incomplete combustion	239.2	1.68
Combustible loss in ashes	290.9	2.04
Radiation and other losses by difference	712.0	5.00
Total	3,946.5	27.70
Heat units utilized in making steam, equivalent evaporation 10.66 lbs. from and at 212 degs. F., per lb. coal	10.298.8	72.30
	14,245.3	100.00

In connection with the above equivalent, it is important to determine, first, whether the steam is saturated or contains the quantity of heat due to the pressure; second, whether the quantity of heat is deficient so that the steam is wet; and third, whether the heat is in excess of the pressure or the steam superheated. The quality of steam given off by the boiler bears directly on the work being performed by the boiler, and its efficiency, and if it is not taken into consideration, the evaporation performance of the boiler can be made to show any efficiency desired.

A simple method of testing steam for its condition is to use a barrel calorimeter which will give fairly accurate results within 2 per cent of the true quantity, when carefully operated. The steam to be tested should be taken from the steam pipe near the boiler by means of a perforated ½-in. pipe inserted into the pipe leading from the boiler, so that no condensed steam can enter the test pipe, and provided with a valve. The steam is carried through a hose which is well wrapped in felt to prevent condensation, and led to a barrel set on platform scales holding about 400 lbs. of water, and provided with stirring vanes, so that the water can be kept in rapid circulation. After carefully weighing the barrel and the water, steam is turned on through the hose and allowed to blow off until the pipe is thoroughly warmed. The hose is then inserted in the barrel so that all steam is condensed, and the water is kept in rapid circulation. The steam pressure on the boiler tested should be noted and kept uniform.

In order to determine the temperatures, a thermometer is inserted in the water and watched until the temperature arises to about 110 degs. F. The hose is then quickly withdrawn and exact temperature noted, and the barrel carefully reweighed. An error of $\frac{1}{10}$ of a pound in weighing the water or $\frac{1}{2}$ a degree in temperature will cause an error of over 1 per cent. in the calculation of moisture in the steam.

The original weight of water is, say, 404 lbs., and its temperature 34 degs. F.; the final weight of water is 435 lbs., and the temperature 106 degs. F.; the boiler pressure is 60 lbs. To find the percentage of moisture, proceed as follows:—

H = total heat of 1 lb. of steam at 60 lbs. pressure........................ 1,175.6
T = total heat of 1 lb. of water at temperature of steam at observed pressure.. 307.10
N = temperature of condensing water in barrel, original 34 degs. F.
N_1 = temperature of condensing water in barrel, final 106 degs. F.
W = weight of condensing water, corrected for water equivalent to apparatus... 410 lb.
U = weight of steam condensed 435—410 lbs.............................. 25 lb.

$$\text{Percentage of moisture}-100=\frac{1}{H-T}\left[\frac{W}{U}(N_1-N)-(T-N_1)\right].$$

Substituting values:

$$\text{Percentage of moisture}-100=\frac{1}{1{,}175.6-307.1}\left[\frac{410}{25}(106-34)-(307.1-106)\right]=122.7$$

This shows that in the case assumed above, there was 122.7—100 = 22.7 per cent moisture in the steam, indicating heavy priming in the boiler.

The appearance of a steam jet will indicate roughly with a little experience the quality of steam; if a jet flows into the air a change of 1 per cent saturated steam is easily discernable. If the jet is transparent, close to the orifice or even a light grayish color, it may be assumed to be nearly dry, and the ordinary methods will not determine the water in the steam, but if the jet be strongly white, with experience the amount of water may be judged up to about 2 per cent; beyond this, a calorimeter only can determine the exact amount. Ordinarily a boiler should not give more than 2 per cent moisture unless foaming or priming; the water level should not be carried too high, or the boiler forced beyond its capacity, which generally increases the percentage of moisture. If a boiler gives normally more than 1½ per cent moisture, there is something wrong in its construction or connection, and it is very uneconomical to use wet steam in the engine cylinder, as it increases greatly the losses due to cylinder condensation and the danger of entrained water in the cylinder.

These tests have so far referred to continuous boiler tests, but actual conditions that arise in station practice change greatly the demands on the boiler during different periods of the day, and there are hold-over losses on boilers not delivering any steam whose values, for economical management of the boilers, should be known. Coal burnt to keep a boiler in steaming condition is lost, and it has been proposed to use a cheaper grade of coal for the purpose, which will keep a uniform low fire and give to the boiler those heat units which are lost in conduction and radiation.

The report of the committee on data of the National Electric Light Association, gives the following figures for hold-over losses. In this case the boiler is shut off from the main steam supply. No water is added and the coal is simply to supply the constant losses. A boiler runs 16 hours a day at an average rate of 12 lbs. of coal per square foot of grate per hour, and stands over the other eight hours with a consumption of ½ lb. of coal per square foot of grate surface; while idle it will consume 2.04 per cent of the whole. If it runs twelve hours and stands twelve hours, the coal cost idle will be 4 per cent of the total expense. The data given for different boilers is as follows;—

A Philadelphia station requires 1 200 lbs. of coal to keep up a pressure of 125 lbs. on two water tube boilers, each having 59 sq. ft. of grate surface; that is, .424 lb. per sq. ft. per hour. A five days' test on a horizontal tubular boiler showed a consumption of .35 lb. per sq. ft. of grate; another water tube boiler showed .5 lb. of coal per sq. ft. of grate per hour.

Waste in the form of leakage, whether from wet steam or actual escape, has reached in three stations 3,500 lbs., 2,000 lbs., and 500 lbs. Auxiliary uses of steam, such as heating and feeding water to boilers, are drags on the boiler, but have to be considered in the total boiler room efficiency, and bring down the total plant efficiency.

Boiler room records are usually kept on printed forms by the foremen of the different shifts of firemen, and the form adopted by the different stations will depend on the data obtained. A form largely used is given below:

DATE...............WEATHER..............FOREMAN.................

TIME OF COMING ON.............,BOILER PRESSURE, MAXIMUM, 161; MIN., 142.

1. Boiler number.	1.	2.	3.	4.	5.	6.
2. Condition	Banked	Fired	Fired	Sh't d'wn	Banked	Sh't d'wn
3. Water meter, lbs.........	110,684	117,680	111,466	111,480	18,705	18,971
4. Coal fired to each boiler	1,306	7,141	6,400	....	1,685	....
5. Started up at............	5.10 P.M	....	....	....	6 P. M.	....
6. Shut down at	11.06	12 M.N.	....	....	....	....
7. Water meter, end of run	122,384	163,760	178,600	111,485	123,240	18,971

8. Temperat. of feed water, 218° F., 106° F.
9. Weight of ash.........................
10. Natural draught, inches...........¾—⅞
11. Forced draught, inches..........1¼—1½
12. When started up................5.45 P.M.
13. When shut down................9.30 P.M.
14. How fed...........................Pump
15. Temperature of uptake ....618°
16. Per cent of CO_2......................15%—6%

REMARKS.

Item 9 is usually taken at stated intervals when ash is hauled away and not for each boiler, but is entered on this form. Items 10, 11, 12 and 13 (where forced draught is used), are important to know when forced draught is started up to determine if it was not put in operation too soon for the power demand on the station; also to know the natural draught conditions due to the weather. Item 14, the method of feeding water, whether injector or pumps were used, affects the economy of operation of the boiler plant. Item 15, temperature of up-take, gives a value depending upon firing and arrangement of dampers. Item 16 gives from the composimeter the condition of draught for the proper consumption of the coal burned. A recording pressure gage is the only means for showing whether the proper maintenance of boiler pressure has been uniform throughout the run. but from the above figures all the commercial efficiencies and losses in the boiler room can be computed.

SECTION III.—THE TRACK.

LOCATION.

The location of street railway tracks in streets and highways is largely controlled by ordinances, which specify the distance from the rail to the curb or from the center of the track to the curb, the distances between track centers of a double track road, the type of rail head, its location regarding the street level, etc. In country and interurban roads, however, a greater latitude as regards track construction is usually allowed the engineer. The question of crossings, trees to be removed, roadway obstructions, character of roadbed, and cubic yards of embankment necessary to cut or fill have all to be considered with regard to each section of the road, to ascertain which location had best be adopted; and where the right of way has to be secured through private property its cost is another factor.

LEVELS.

As the possible speed and energy required to make a trip between two terminal points are largely determined by the grades over which the road must be built, the profiling and determining of grades and levels is one of the necessary duties of a railway engineer, particularly in interurban railway construction. The details of the methods employed in laying and profiling can be found in any text book on surveying, but the simpler methods are given here to assist the street-railway engineer in plotting grades.

The elevation of any part of a road is always given as higher than some level surface of known or assumed elevation, and in order that the elevations may all be positive, this surface should be selected below any elevation to be measured. This surface is called "The Datum." The elevation of the datum is always zero and the elevation of any point is its vertical height above the datum. The point selected for a datum should be permanent and is called a bench mark; in a long route several bench marks are taken for convenience, but all the elevations are figured from the datum, and the elevations of the other bench marks are determined in reference to the one first selected. The instrument generally used for levels is a spirit level, mounted on, and parallel to, a telescope, the field of which is provided with cross hairs, so that the line of sight through the intersection of the cross hairs is horizontal when the bubble stands in the middle of its tube. Then any point in the line of the horizontal cross-hairs through the telescope is on the same level as the cross-hairs.

To ascertain levels, the instrument should be set up and levelled at a point higher than and in full view of the first bench mark, on which a surveyor's rod should be held vertically. When the line of sight is turned on the rod the point of the rod covered by the horizontal cross-hair is then on a level with this cross-hair, and the cross-hair is higher than the bench mark by the distance on the rod from the bench mark to the point where the horizontal cross-hair crosses the rod. Add this distance to the height of the bench mark, and we obtain the height of the instrument, technically known as the "Height of Instrument," and sometimes designated by H. I.

Having obtained the height of the instrument above the datum line, any point lower than the cross-hairs can be easily found by taking the reading of the rod upon it; the reading subtracted from the height of the instrument gives the elevation above the datum of the point on which the rod is set. No elevation of a point can be obtained if the rod, when placed on that point, is not in the line of sight of the instrument; in this case the instrument must be moved to a new position, either higher or lower than before as the case may require.

Before the instrument is removed a temporary bench, called a "turning point" and designated by T. P. or Peg, must be established, and its elevation determined; as for any other point the reading of elevation on the rod being taken on the turning point, the instrument can be removed to another position. After it is properly levelled up, the new height of the instrument is obtained by a new reading on the same turning point; since the cross-hairs are higher than the point, this reading, added to the elevation of the point, gives the height of the instrument.

Records are kept of the levels of the different stations as they rise above the datum or zero level selected, and the distances between stations. These stations can be 400 feet from the instrument and accurate work done. These distances and elevations are then laid out on profile paper to any desired scale. For convenience, in drawing the profile, the entire length is considered as straight.

The limiting grade, up which it is safe to carry an electrical equipment, except under special conditions, is about 15 per cent. Where traffic is heavy, it is questionable whether considerable investment could not often be profitably made to obviate a heavy grade on account of the slow time made, together with the heating and consequent depreciation of the equipment.

The cost of operating over grades is governed by local conditions so that it is not amenable to any general treatment. The elements that enter in this calculation, however, can be indicated by an assumed case: Suppose that a grade affects such a reduction in the speed that an extra equipment has to be operated all the time to maintain the proper schedule between cars, then the cost per year to operate this equipment would be the interest on the amount of money which would be profitable to expend to avoid or reduce the grade, the other consideration being the greater depreciation of all equipments ascending the grade and the additional hazard on descending the grade.

Cuts and Fills.—To estimate cubic contents of excavations or fillings assuming parallel end faces, parallel top and bottom surfaces, and uniform section

l = length.
dp = perpendicular height or depth.
wd = width at bottom of cut or top of fill.

Dimensions in linear feet, results in cubic yards.

Slope 1 to 1:

$$\text{Cu. yds.} = .03704l \times dp(wd + dp).$$

Slope 1½ to 1:

$$\text{Cu. yds.} = .03704l \times dp(wd + 1\tfrac{1}{2}dp).$$

Slope 2 to 1:

$$\text{Cu. yds.} = .03704l \times dp(wd + 2dp).$$

Slope 2½ to 1:

$$\text{Cu. yds.} = .03704l \times dp(wd + 2\tfrac{1}{2}dp).$$

To estimate cubic contents of wedge-shaped end of cut, assuming horizontal base and uniform decrease in depth from maximum to zero, Slope 1 to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 2dp).$$

Slope 1½ to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 3dp)$$
$$= .018516l \times dp(wd + dp).$$

S.ope 2 to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 4dp).$$

Slope 2½ to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 5dp).$$

The above formulæ are true for fill having horizontal top surface, and uniform decrease in depth from maximum to zero.

To estimate cubic contents of wedge-shaped end of fill, assuming horizontal base and uniform decrease in depth from maximum to zero.

Slope 1 to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 4dp).$$

Slope 1½ to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 6dp).$$
$$= .018516l \times dp(wd + 2dp).$$

Slope 2 to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 8dp).$$

Slope 2½ to 1:

$$\text{Cu. yds.} = .006172l \times dp(3wd + 10dp).$$

Shrinkage.—In estimating the relative amounts of excavation and embankment required, allowance must be made for difference in the spaces occupied by the material before excavation and after it is settled in embankment. The various earths will be more compact in embankment, rock less so. The difference in volume is called shrinkage in the one case, and increase in the other.

	SHRINKAGE IN 1000 CU. YDS.	
Material.	Of Excavation.	Of settled embankment.
Sand and gravel	80 cu. yds.	87 cu. yds.
Clay	100 "	111 "
Loam	120 "	136 "
Wet soil	150 "	200 "
	INCREASE IN 1000 CU. YDS.	
Rock, large fragments	600 cu. yds.	375 cu. yds.
Rock, medium fragments	700 "	413 "
Rock, small fragments	800 "	444 "

Thus an excavation of sand and gravel measuring 1000 cu. yds., will form only about 920 cu. yds. of embankment; or an embankment of 1000 cu. yds. will require 1087 cu. yds. of sand or gravel measured in excavation to fill it; but will require only 587 cu. yds. of rock excavation, the rock being broken into medium-sized fragments; while 1000 cu. yds. of the later, measured in excavation, will form 1700 cu. yds. of embankment.

For Weights of Earths and Stones, see pages 11 to 13.

TRACK LOCATION.

Track is made up of straight and curved track; the straight track is called "tangent" and the curved may be a simple curve, that is, a circle struck from the center so as to be tangent to both tracks which it connects. The length of this radius can be found by erecting at the adjacent ends of the tangent track vertical lines, which will intersect at the center of the curve to be struck. To correctly join these two tangents in street railway work the curved position of the track is defined by the radius of this curvature. Steam roads usually adopt a different nomenclature, which is the number of degrees of curvature, included in an arc 100 ft. long. With the short curves used in street railways it is readily seen that this designation would not be suitable

The survey of a line of track is always made from the middle of the track by setting a row of stakes where the center line of the track passes, and the rail is gaged both ways from this center.

Before these center points are located by the engineer in city streets, all knowledge possible should be obtained regarding existing subterranean structures, which may be beneath the surface or on the street surface, in order that they may not be disturbed nor their usefulness interfered with. All city maps of the city, gas, water, subway systems, sewage, etc., become useful if reliable. Usually all obstructions that are in direct line of the rail can be relocated, but in the case of water and gas mains, any street surface structures leading to, or metallicly connected with, this piping system should be removed at least two feet from the rails, and if possible cement should be interposed between these two structures. Otherwise current may be deflected into these piping systems from the metallic connections made in this way and damage from electrolysis may result.

In city work where curves occur, it is desirable, before commencing work, first to lay out each curve on a fairly large scale, say 1 in. = 5 ft., drawing in the tangent tracks which meet at this corner, also any obstruction in the street such as sewer covers, man holes, gas or water gate boxes, also the curb line and any obstruction on the corner if it should offer any possibility of hazard to a passenger standing on the running board of an open car in passing around the curve. After all these details have been drawn in the map the curves can be thrown in, as explained later.

In laying road on paved streets with traffic on them, it is best to set stakes at an offset from the line of track out of line of the traffic, about 50 ft. apart on straight track, and close enough together on curves to have at least two points opposite each rail. In special work a point should be set opposite the heel and toe of each switch.

TYPES OF ROADBED.

Specifications for Street Railway Track in Cities.—Pratt & Alden give the following specifications for railway track, located in city streets.

Construction.—Nine inch girder rail on wooden ties, broken stone ballast and granite block pavement.

1. *Work to be Done.*—The work to be done consists of the construction of a single track on.........., ..., and .... Streets, between .... Street and..........Street, in the City of.........., State of ....

2. *Tools and Labor.*—The contractor is to furnish all necessary tools, apparatus, and other means of construction, and do all the work required for the above construction.

3. *Material.*—The company will furnish and deliver to the contracter, at its yard located on .... Street, all material required for the above construction except such as are not to be part of the finished construction, which will be furnished by the contractor.

4. *Interference with Traffic.*—The street must not be torn up for a greater distance than 500 ft. in advance of the finished paving. The contractor must so arrange his work and deliver the material upon the street as to obstruct public travel as little as possible, and a roadway must be kept free on at least one side of the street for public travel.

The contractor shall use all necessary precautions to prevent accidents by maintaining suitable barriers and by keeping lights burning at night.

5. *Grading and Excavation.*—The roadbed is to be excavated to sub-grade, which will be 24 ins. below the finished grade of the street. This excavation is to extend....ft. each side of the center line of track. If any further width of excavation is required, it will be directed by the engineer in writing, and paid for under clause *c*, paragraph 17. All material removed from the excavation is the property of the company, and must be promptly removed by the contractor and deposited in such places and in such manner as may be designated by the engineer. It shall not, however, be hauled a distance greater than....ft., except as provided for under clause *f*, paragraph 17.

No plowing will be allowed which disturbs the material below 6 ins. above sub-grade.

6. *Sub-drains*—If considered necessary by the engineer, a trench will be dug in the center of the roadway to such depth and grade as he shall prescribe. After thoroughly compacting the bottom of the trench, a....in. porous tile-drain shall be laid and such connection made with the sewers or other drains as the engineer may direct. The trench is then to be refilled with clean gravel filling, in layers not exceeding 12 ins. in thickness. Each layer is to be thoroughly compacted by ramming before another layer is added.

7. *Preparing Sub-grade.*—The sub-grade shall then be thoroughly rolled to the satisfaction of the engineer with a roller weighing not less than ....lbs. per inch of roller. If any portions of the sub-grade cannot be reached by the roller, such portions shall be sprinkled with water and thoroughly compacted by ramming. If any spongy or vegetable matter, or material which cannot be rolled, is found in the excavation, it must be removed and the space below sub-grade filled with clean gravel filling. The roadbed shall be in a moist condition when rolled, and if dry must be moistened by the contractor.

8. *Ballast.*—Upon the sub-grade, prepared as above described, there shall be spread a layer 5 ins. thick of broken-stone ballast, composed of stones not larger than 2½ ins. in their largest dimension. This layer shall be thoroughly compacted by rolling with the roller heretofore described, or by ramming in such places as cannot be reached by the roller.

9. *Distribution of Ties.*—Upon this layer of ballast the ties shall be distributed and spaced at intevals of ....ins. on centers. The joint ties will be spaced ....ins. on centers and arranged as shown on plan furnished by the engineer.

10. *Laying Track.*—The rails shall then be placed on the ties and the splice-plates bolted on. Care must be taken not to handle the rails in such a manner as to bend them or mar the heads or flanges. The rails will be spiked with four spikes to the tie. Spikes will be staggered at least 2½ ins. in the tie, and driven in such a manner as to hold the tie at right angles to the track, except when otherwise directed. Brace tie-plates will be used and spiked to the tie with three spikes at intervals of....ft. The rails will be laid with staggered joints, and no joint shall be more than 12 ins. from a line drawn at right angles to the center of

the opposite rail. Care must be taken to place the splice-plates squarely in position, and any scale or rust must be removed from the bearing surfaces of plates and rail. The heads of the bolts must be struck with a two-pound hammer while pressure is applied on a 30-in. wrench to tighten the nuts. The rail ends must be placed in as close contact as possible. The rails must not be bolted up for more than five rail lengths in advance of the finished paving. The gage of the track shall not vary more than $\frac{1}{16}$ in. from the standard on this road, which is ....ft.....ins.

11. *Special Work.*—In laying frogs, switches, and other special work, special care will be taken to maintain line, surface and gage. The latter will be widened on curves if so directed by the engineer, but not otherwise. The straight-track gage at switches and mates will preferably be $\frac{1}{16}$ in. tight. If the special work does not appear to fit, no attempt whatever must be made to force it except by direction of the engineer.

12. *Raising Track and Tamping.*—After the preparation of the track as previously described, the entire track must then be raised to the finished grade and aligned to the lines given by the engineer. The space under the ties must then be filled with broken-stone ballast, composed of stones not larger than 1½ ins. in their largest dimension. This shall be tamped under the ties in such a manner as to secure an even, solid bearing throughout the entire length and width of the tie.

Care must be taken in raising and tamping the track not to deform the rails or splice-bars. The space between the ties is to be filled with the same ballast and thoroughly rammed.

13. *Bonding.*—The rails are to be bonded with the......bond, applied in the following manner: ....

14. *Joints.*—The joints are to be gone over again and each bolt tightened up, striking the head of each bolt with a two-pound hammer, while steady pressure is applied to the end of a 30-in. wrench until they cannot be further tightened.

15. *Preparation of Rail for Paving.*—The recesses under the head and tram of the rail will be filled with concrete in such a manner as to present a vertical surface for the paving to rest against. This concrete shall be composed of one part Rosendale cement, ...parts sand and......parts of broken stone, no piece of which shall be larger than 1 in. in its greatest dimension.

16. *Paving.*—Over the entire portion of the street to be repaved will be spread a layer of clean sharp gravel, not larger than ¾ in. in its largest dimension, and thoroughly compacted until its upper surface is 8 ins. below the finished grade. Especial care must be taken to thoroughly compact that portion between the ties. A layer of bedding sand will then be spread over the gravel of sufficient thickness to bring the granite blocks that are to be embedded in it to the proper grade after they are thoroughly rammed. The blocks are to be covered with clean, fine and dry gravel or coarse sand, which shall be raked and swept until all the joints become filled therewith. The blocks shall then be rammed to a firm, unyielding surface to agree with the section of track as furnished by the engineer. No ramming will be done within 15 ft. of the face of the paving that is being laid. The blocks will again be covered with a layer of clean, fine, or dry gravel or coarse sand, and raked and swept until the joints are filled therewith. The blocks shall then be rammed until made solid and secure. Finally, the paving shall be covered with a layer at least 1 in. in thickness of fine, dry screened gravel.

17. *Measurements.*—The work will be measured and paid for under the following prices:

(*a*) Per foot of single track, including all excavation, refilling, preparation of the sub-grade, ballasting, paving and track-laying.......................................

(*b*) Special work shall be measured on the center line of track, measuring the center line from the separation of theoretical center lines to the similar separation or to a point opposite the farthest joint of special work. Price per foot, determined in this manner, including items mentioned in clause (*a*)..............

(*c*) Price per square yard for excavation, refilling, ballasting, and paving outside the limit of .... ft. from the center line of track, when required by the engineer; ....

(*d*) Price per cubic yard of excavating and refilling measured in excavation for tile-drains...

(*e*) Price per running foot for laying tile-drains and connecting to sewers or drains ....

(*f*) Price per ton per 1000 ft. for hauling material from the excavation a greater distance than ...... ft. from the excavation................................

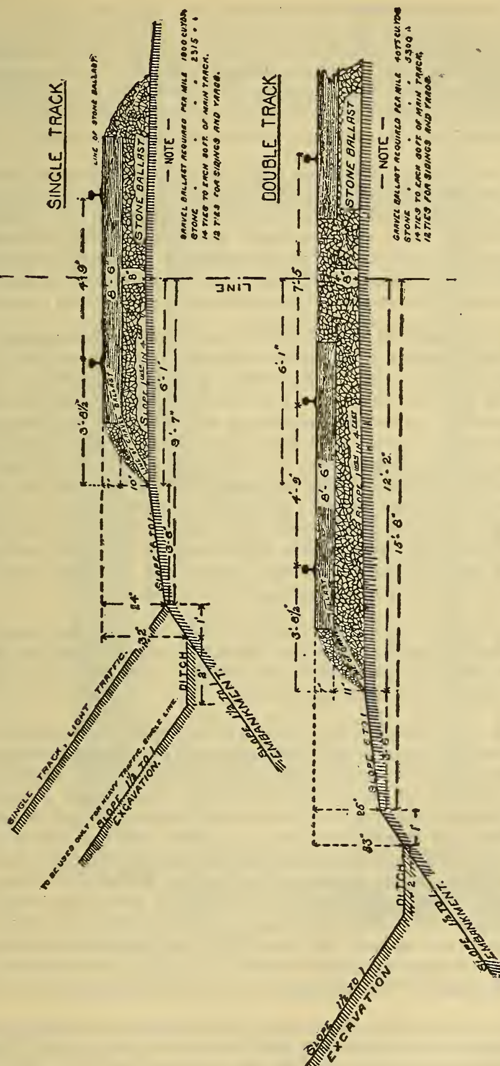
18. *Estimates.*—It shall be understood and agreed by the parties hereto that due measurements shall be taken during the progress of the work, and the estimate of the engineer shall be final and conclusive evidence of the amount of work performed by the contractor under and by virtue of this agreement, and shall be taken as the full measure of compensation to be received by the contractor. The aforesaid estimates shall be based upon the contract prices for the performance of all the work mentioned in these specifications and agreement, and when there may be any ambiguity therein, the engineer's instructions shall be considered explanatory, and shall be of binding force.

SPECIFICATIONS FOR EXPOSED TRACK.

On interurban lines, when the track is exposed, the steam railroad practice can be followed very closely. The Pennsylvania Railroad Company has developed the most complete set of specifications, which indicate that company's method in grading, ballasting and draining. Below is given an abstract from the Pennsylvania Railroad's general specifications, covering such structural features as would be well to follow in cross-country electric track construction. Figs. 72 and 73 show the cross section of single and double track as designated by the specifications.

P. R. R. Specifications for Laying Roadbed.—*Roadbed.*—The surface of the roadbed should be graded to a regular and uniform sub-grade, sloping gradually from the center towards the ditches.

Ballast.—There shall be a uniform depth of 6 ins. to 12 ins. of well broken stone or gravel, cleaned from dust by passing over a screen of ¼-in. mesh, spread over the roadbed and surfaced to a true grade, upon which the ties are to be laid. After the ties and rails have been properly laid and surfaced, the ballast must be filled up as shown on standard plan; and also between the main tracks and sidings where stone ballast is used. All stone ballast is to be of uniform size and the stone used must be of an approved quality, broken uniformly, not larger than a cube that will pass through a 2½ in. ring. On embankments that are not well settled the surface of the roadbed shall be brought up with cinder, gravel or some other suitable material.



FIGS. 72 and 73.—STANDARD ROADBED CONSTRUCTION OF THE PENNSYLVANIA R. R.

Cross-Ties.—The ties are to be regularly placed upon the ballast. They must be properly and evenly placed, with 10 ins. between the edges of bearing surface at joints, with intermediate ties evenly spaced: and the ends on the outside on double track, and on the right-hand side going north or west on single track, lined up parallel with the rails. The ties must not be notched under any circumstances; but, should they be twisted, they must be made true with the adze, that the rails may have an even bearing over the whole breadth of the tie.

Line and Surface.—The track shall be laid in true line and surface; the rails are to be laid and spiked after the ties have been bedded in the ballast; and on curves, the proper elevation must be given to the outer rail and carried uniformly around the curve. This elevation should be commenced from 50 ft. to 300 ft. back of the point of curvature, depending on the degree of the curve and speed of trains, and increased uniformly to the latter point, where the full elevation is attained. The same method should be adopted in leaving the curve.

Joints.—The joints of the rails shall be exactly midway between the joint ties, and the joint on one line of rail must be opposite the center of the rail on the other line of the same track. A Fahrenheit thermometer should be used when laying rails, and care taken to arrange the openings between rails in direct proportion to the following temperatures and distances; at a temperature of 0 deg., a distance of $\frac{5}{16}$ in.; at 50 degs., $\frac{5}{32}$ in.; and in extreme summer heat, of, say 100 degs. and over, $\frac{1}{16}$ in. must be left between the ends of the rails to allow for expansion, The splices must be properly put on with the full number of bolts, nuts and nut-locks, and the nuts placed on inside of rails, except on rails of 60 lbs. per yard and under, where they shall be placed on the outside and screwed up tight. The rails must be spiked both on the inside and outside at each tie, on straight lines as well as on curves, and the spikes driven in such a position as to keep the ties at right angles to the rails.

Switches.—The switches and frogs should be kept well lined up and in good surface. Switch signals must be kept bright and in good order, and the distant signal and facing-point lock used for all switches where trains run against the points, except on single track branch roads.

Ditches.—The cross-section of ditches at the highest point must be the width and depth as shown on the standard drawing, and graded parallel with the track, so as to pass water freely during heavy rains and thoroughly drain the ballast and roadbed. The line of the bottom of the ditch must be made parallel with the rails, and well and neatly defined, at the standard distance from the outside rail. All necessary cross-drains must be put in at proper intervals. Earth taken from ditches or elsewhere must not be left at or near the ends of the ties, thrown up on the slopes of cuts, nor on the ballast, but must be deposited over the sides of embankments. Berm ditches shall be provided to protect the slopes of cuts, where necessary. The channels of streams for a considerable distance above the road should be examined, and brush drift, and other obstructions removed. Ditches, culverts, and box drains should be cleared of all obstructions and the outlets and inlets of the same kept open to allow a free flow of water at all times.

Road Crossings.—The road-crossing planks shall be securely spiked; the planking on inside of rails should be ¾ in., and on outside of rails it should be ⅛ in., below the top of rail, and 2½ ins. from the gage line. The ends and inside edges of planks should be beveled off as shown on standard plan.

EXAMPLES OF TRACK CONSTRUCTION.

Track Construction on Concrete Girders.—This form of track construction does away with the frequently spaced tie and substitutes a lateral bearing for the rail. The rails are tied together at intervals, but depend upon the concrete foundation for their support. This construction is especially useful

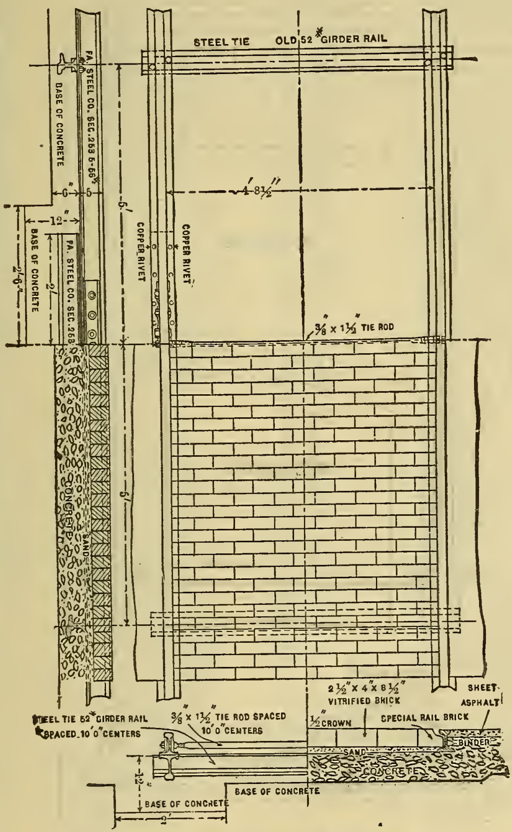


FIG. 74.—SCRANTON, PA., TRACK CONSTRUCTION.

where paving such as concrete, brick or asphalt already exists on the street to be tracked, as trenches only have to be cut in the paving for the rails and their foundations with occasional cross cuts for the tie rods, thus reducing the cost for repaving.

Scranton, Pa., Construction.—The rail is a 5-in. T, weight 57 lbs., in 60-ft. lengths and with a 6-bolt joint. Underneath each joint is an inverted section of same rail, 4 ft. long, extending 2 ft. each side of the joint and riveted to the rail by eighteen ¾-in. rivets; four of these rivets are copper for bonding. The concrete

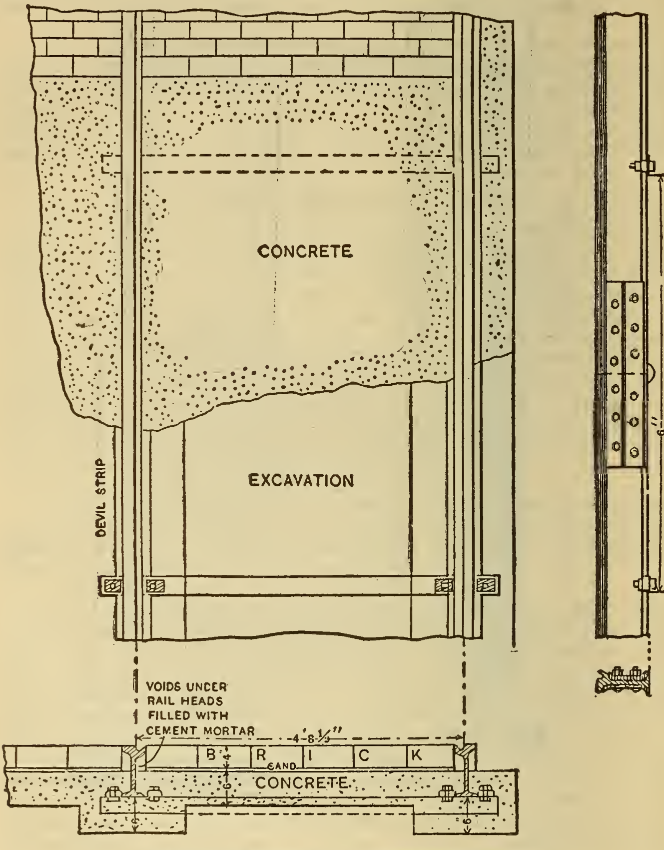


FIG. 75.—DETROIT TRACK CONSTRUCTION.

is laid 6 ins. below rail except for 2 ft. 6 ins. each side of the joint where it is 12 ins. below the rail. The ties which are old 52-lb. girder rails, are spaced 10 ft. apart and the rails are bolted to them. There is also a tie rod ⅜ ins. x 1½ ins. between each tie. For details of construction see Fig. 74.

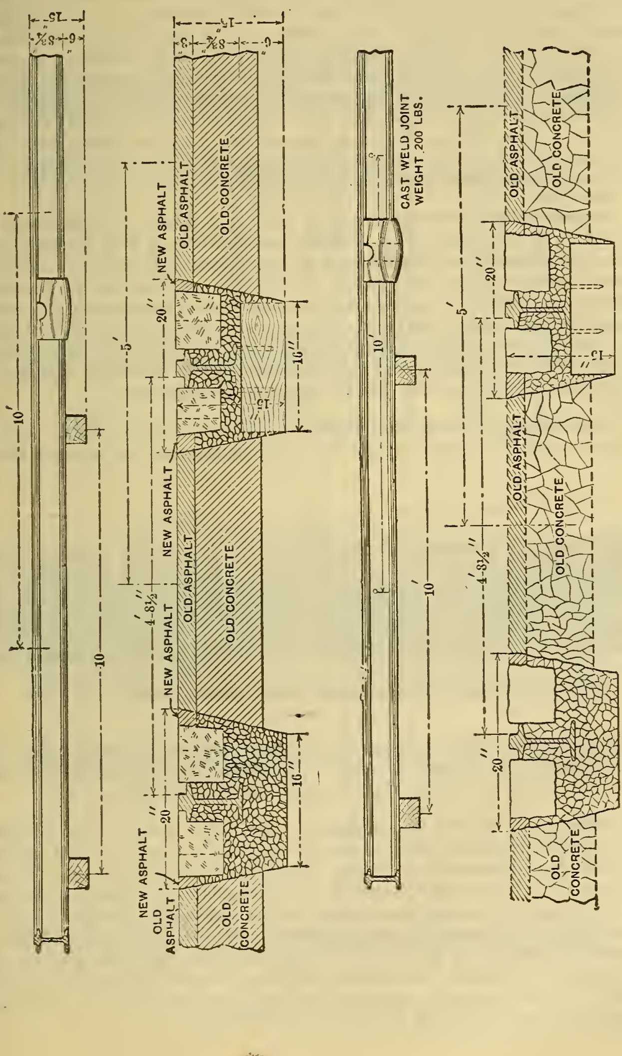


FIG. 76.—KANSAS CITY TRACK CONSTRUCTION.

Detroit Track Construction.—The rail is a 9-in., 100-lb. girder with steel ties 5-ft. centers. The ties are channels 7 ins. wide, 7 ft. long and ⅜ in. thick, with flange 1⅛ in, deep. Concrete was laid 6 ins. below base of rail and tamped under tie, also laid on top of ties and carried up to within 1½ in. of the base of the paving. Where concrete stringers were used, the trench was 15 ins. deep and 1 ft. wide. A layer of concrete composed of 1 part Portland cement, 4 parts Louisville cement, 8 parts sand and 16 parts broken stone was then laid in bottom of the trench to depth of 6 ins. The rail used in this construction was 7 ins. high; the space between the base of rail and base of concrete was grouted with 1 part Portland cement, 1 part sand and 3 parts clean fine gravel. Tie rods were used 10 ft. apart. For details of construction see Fig. 75.

Kansas City Construction.—The foundation trench is 20 ins. wide on top, 16 ins. on botton and 15 ins. in depth, so there will be 6 ins. below the rail when it is on grade. At 10-ft. intervals are placed wooden blocks 8 ins. x 10 ins. x 16 ins. to which the rails are spiked. After gaging and aligning the track, the trenches are filled with concrete made of 2 parts sand, ½ part Portland cement, ½ part domestic cement and 5 parts crushed stone small enough to pass through ½ in. ring, all by measure. Temporary splice bars are bolted on at rail joints which eventually are cast welded; the metal for the cast weld being composed of ½ pig iron and ½ scrap iron. See Fig. 76 for this construction.

Los Angeles Track Construction.—The rail is a 6-in., 60-lb., 60-ft. T. The managers of the Los Angeles Railway Company were the pioneers in the

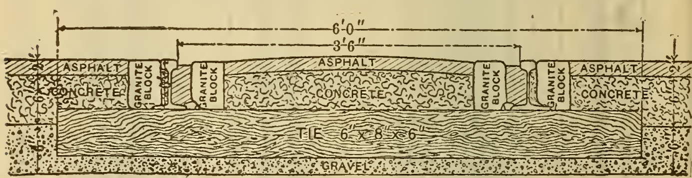


FIG. 77.—LOS ANGELES TRACK CONSTRUCTION.

bringing of these long rails across the continent, and report finding no difficulty or additional expense in transportation. In a recent shipment of 500 tons only three rails had to be straightened. For details of construction see Fig. 77.

Milwaukee Track Construction.—The rail is a 6-in., 72-lb. Shanghai section in 60-ft. lengths and is laid on cedar ties 6 ins. x 8 ins. x 7 ft., 2-ft. centers. Under pavements which have concrete foundations the ties are laid on a 6-in. bed of cement, and in other streets broken stone ballast is used. The Falk cast-weld joint is used. In exposed track which is cast welded slip joints are provided every 500 ft. The contraction and expansion in exposed track has been found to amount to about 1¼ in. per 100 ft. of track, so at the slip joints the rails are sometimes 6 ins. apart. The standard suburban roadbed of this company consists of a 56-lb. T, 4¼ in. 60-ft. rail laid on broken stone or gravel ballast, with Weber joints. See Fig. 78 for these constructions.

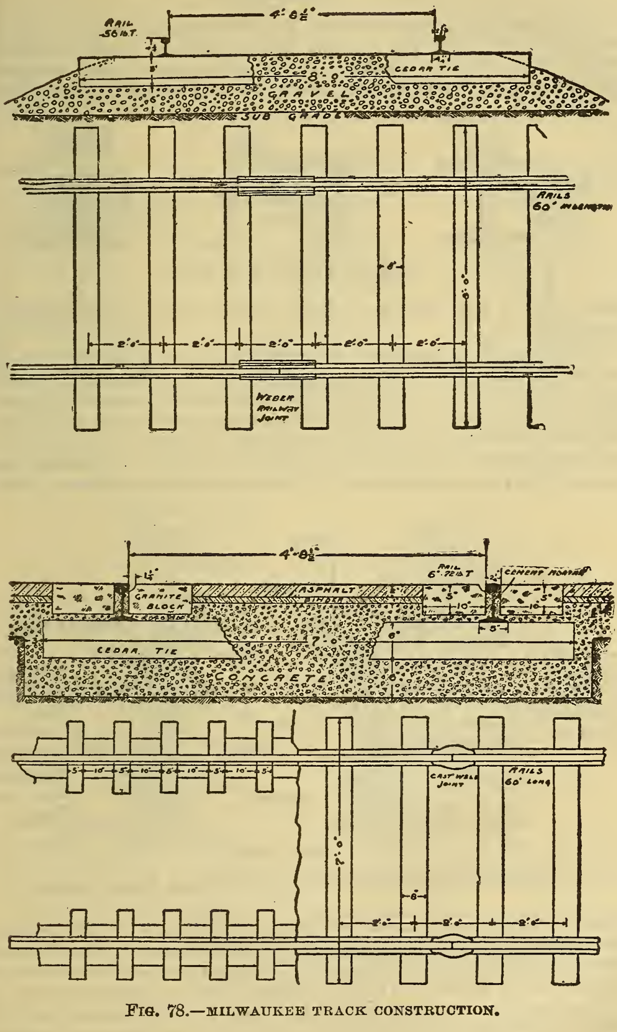


FIG. 78.—MILWAUKEE TRACK CONSTRUCTION.

RAILS.

Sections.—Rails have been rolled in nearly every conceivable shape, which would serve the purpose of a rail. The forms illustrated are those most used in modern street railway practice. Fig. 79 gives some general sections, the box girder being nearly obsolete; the T and the girder are the prevailing rail-

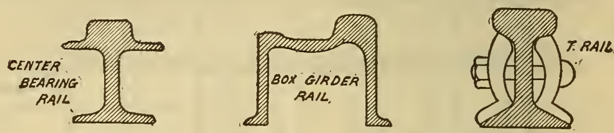


Fig. 79.—GENERAL RAIL FORMS.

forms now in use. Fig. 80 gives the nomenclature for the different parts designated.

Taking up the grooved type of girder rail, Fig. 81 shows the Crimmins or original rail adopted by the Metropolitan Street Railway Company of New York City. The peculiarity of this rail consists in its long lip, extending beyond the guard. This allows of the pavement being laid adjacent to the rail, and carries the street traffic which tracks on the rail, thus preventing to some extent the wearing of grooves along the pavement adjacent to the rail. Fig. 82 shows the later section of the girder rail adopted by the Metropolitan Street Railway. The head

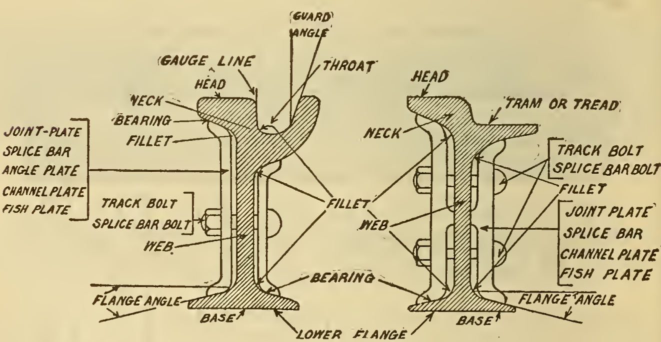
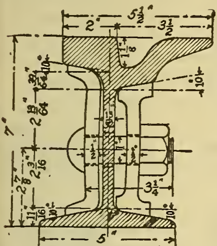


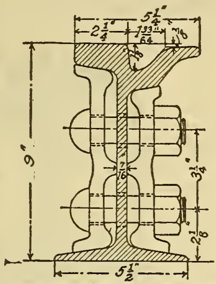
Fig. 80.—RAIL NOMENCLATURE: SIDE BEARING GIRDER RAILS.

differs from that shown in Fig. 81 in that the width of the lip is reduced, and the tram is dropped ⅛ in. below the head of the rail; the head has also been thickened, and the rail has been increased to a depth of 9 ins. to make it stiffer. Fig. 83 gives the grooved rail for the Brooklyn Heights Railroad, designed by J. C. Brackenbridge. Here the web has been moved nearer the center of the head of the rail. Fig. 84 gives the flat tram used by the same company. The Brooklyn road uses the support more nearly under the head of the rail, which produces less canting effect upon the rail and its bearing on the passing of an equipment. Fig. 85 shows the section adopted by the Boston Elevated Railway Company for its city surface lines. Fig. 86 shows the section used in Washington, D. C. This is used in recently installed conduit roads, and the pavement is asphalt throughout. Fig. 87 shows the New Orleans section which has many of the advantages of a center bearing rail in its freedom from dirt. Fig. 88 gives the standard T-rail section of the American Society of Civil Engineers, which has been largely adopted throughout the country, the dimensions and weight varying



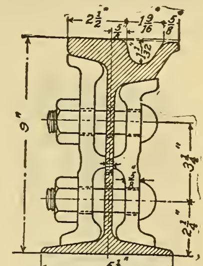
CRIMMINS RAIL.

FIG. 81.



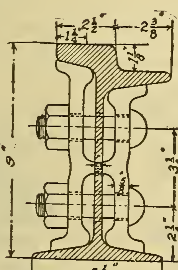
STANDARD RAIL OF METROPOLITON STREET RAILWAY.

FIG. 82.



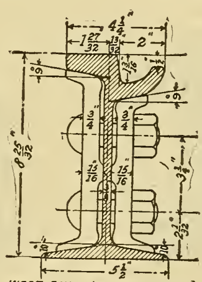
STANDARD RAIL OF BROOKLYN HEIGHTS RAILWAY.

FIG. 83.



STANDARD RAIL OF BROOKLYN HEIGHTS RAILWAI

FIG. 84.



WEST END STREET RAILWAY RAIL.

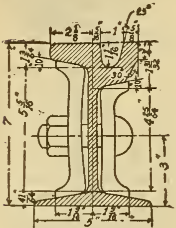
FIG. 85.

to meet the different traffic conditions. Figs. 89, 90 and 91 show some of the rail sections used on some of the important steam roads in this country which could be used in street railway work.

A good track is stiff enough to resist flexion, has a rail joint as strong and rigid as the rail itself, is kept clean by the passage of the cars and presents small obstruction to traffic. The weight and depth of the rail are determined by the traffic, weights and speeds of equipments, the pavement and the limiting profitable cost of construction and track maintenance.

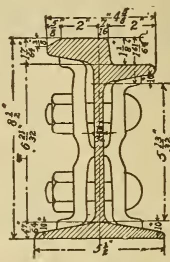
It is most important that the head and groove of a rail be kept clean. It is not generally understood how much extra demand on a power station a dirty track will make. In a test made on a track, which was covered with dust and dirt, the starting current was 212 amps., the car started slowly on the second notch of the controller, and 3.28 kw-hours per car mile were consumed under regular traffic conditions. After cleaning the track the car started with 96 amps. on the first notch and the kw-hours per car mile fell to 1.24. This, however, can not be cited as a fair average for the track was so located as to readily collect dirt

It will also be noticed that the head of a rail that has dirt or dust over it will not present the polished condition of a clean track, but will be discolored and pitted, due to the arcing between the wheel and rail. This character of rolling



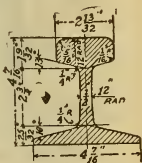
WASHINGTON RAIL.

FIG. 86.



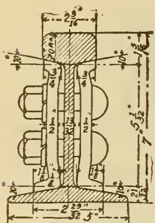
NEW ORLEANS RAIL.

FIG. 87.



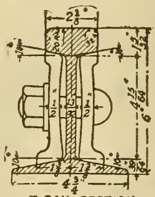
STANDARD RAIL OF THE A.S.C.E.

FIG. 88.



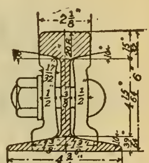
T-RAIL SECTION.

FIG. 89



T-RAIL SECTION.

FIG. 90.



T-RAIL SECTION.

FIG. 91.

surface presented to the wheel increases the power required to propel the equipment over the track. With a grooved rail the dirt packs in the groove and the weight of the equipment is partly rolled on the flange of the wheel over the packed dirt in the groove. The center bearing rail, which includes the T-rail, is the most economical of power and most desirable in many other respects. The objection used against it is that it affords more obstruction to vehicles crossing the track and as vehicle wheels will not run on the head two grooves are often formed in the pavement on either side of the rail.

Street Traffic.—Street traffic has to be carefully considered in each question of roadbed construction. In the smaller towns where it is light a rail head can be used which will afford a track for the vehicles. But a rail that forms a good wagon way will attract wagons to it and reduce the schedule time possible for the cars following them. What has to be cared for is proper surfacing so that buggy wheels are not wrenched in turning out from the track, the principle element of damage.

In larger cities where traffic is heavy, the condition of an unbroken street surface should be attained as nearly as possible. Here a full-grooved rail will accomplish the desired results more nearly than any other type. With the other sections there is a guide way to keep the vehicles to the track by the projecting head of the rail. The sections of the half-grooved type, is a compromise between the grooved rail and flat tram rail. The full flat tram causes greater straining to vehicles when turning out, and the width of the tram has no useful purpose when viewed from the street railway point of view.

Light carriages have tires of a width of 1¼ in.; delivery wagons, 1½ in. and heavy wagons from 2 ins. to 4 ins. and wider. The usual thickness of a car wheel flange is from ⅞ in. to 1 in. To allow play to the wheels and for the difference of ¼ in., which is the undergage usually allowed for setting wheels, the groove should be at least 1¼ ins. wide at top. It will be noticed that the groove is usually sloping with a large guard angle so that the wheel flange will throw out dirt that accumulates in the groove. In a straight sided groove the dirt is packed by the rolling flange, and the power required is increased.

A grooved rail which has a groove not wider than 1¼ ins. will not form a tramway for vehicles, and they will follow more the street to the side of the track and reduce the wear on the pavement adjacent to and between the rails.

Pavement.—In pavement with asphalt laid against the rail, the full-grooved rail is largely used, as any other attracts traffic and concentrates vehicular traffic on or parallel to the rails, which soon wears the asphalt in deep grooves and breaks up the surface of the pavement. Also in cold climates the iron rail against the asphalt makes it brittle and depreciate rapidly. In order to reduce this wear at these points, a granite toothing stone is first laid against the rail, consisting of alternate headers and stretchers, and the asphalt pavement is brought to this surface. There have been made bricks which overlap the tram of the rail, forming a grooved rail and reducing the breadth of the tram. Where a T-rail is laid in paving, the paving is laid directly against the rail and a car truck with larger flanged wheels than ordinarily used and heavily weighted is drawn over the road to form the groove in the paving stone.

The depth of the rail is regulated somewhat by the character of pavement used. Brick or asphalt require a sub-base and should not rest on the ties, as this will soon give the pavement an unequal setting. Where this pavement is used, therefore, a 7-in. girder, at least, is required. With a 6-in. Belgian block there is required 1 in. of sand for a bed and a deep rail must also be used.

In macadam pavement the T section forms the best rail, as the grooved rail would be continually filled with dirt, and the flat tram would attract traffic which would put excessive wear on the pavement adjacent to the track.

RAILS: SPECIFICATIONS, COMPOSITION AND TESTS.

Illinois Steel Company Standard Specifications for Steel T-Rails.—

1. The section of the rail throughout its entire length shall conform to the American Society of Civil Engineer's Standard......lbs. per yard.

The fit of the fishing or male templet shall be perfectly maintained. When the rolls are new, the section of the rail may be $\frac{1}{64}$ in. low. As the rolling proceeds, a variation not exceeding $\frac{1}{32}$ in. in excess of height over templet may be permitted in a delivery of 10,000 tons of rails, after which the rolls must be reduced to standard height of such sections.

The standard of measure to be Brown and Sharpe's United States standard steel vernier caliper rule.

2. The weight of the rail shall be kept as near to......lbs. per yard as is practical after complying with Section 1. The rails shall be accepted and settled for according to actual weights.

3. The standard length of rail shall be 30 ft., at a temperature of 70 deg., Fahr. Shorter rails, having length of 22 ft. to 29 ft. inclusive, shall be accepted to the extent of 10 per cent of the entire order. A variation in length of ¼ in. over or under the specified length will be allowed.

4. Care to be taken in cambering the rails so as to reduce the amount of work in the straightening press to a minimum. The rails must be kept straight in all directions as to both surface and line, without twists or kinks.

5. The rails must be smooth on the head and base, and free from all mechanical defects and flaws, and must be sawn square at the ends; the burrs made by the saws must be carefully chipped and filed off, particularly under the head and on the top of the flange, to ensure proper fit of the angle-bars.

6. The drilling for the bolts to be in strict conformity with the blue print attached, or the dimensions given. Holes imperfectly drilled to be filed to proper dimensions. All holes must be accurate in every respect.

7. The section number, name of maker, year and month, to be rolled on the side of the web. The number of the heat to be stamped in the side of the web.

8. The chemical composition of standard rails under 70 lbs. per yard to be as follows:

Carbon	.37 to .45 of 1 per cent
Sulphur not to exceed	.05 " "
Phosphorus not to exceed	.10 " "
Silicon	.07 to .15 " "
Manganese	.70 to 1.10 " "

The chemical composition of standard rails 70 lbs. and over per yard to be as follows:

Carbon	.45 to .55 of 1 per cent
Sulphur not to exceed	.05 " "
Phosphorus not to exceed	.10 " "
Silicon	.10 to .20 " "
Manganese	.80 to 1.00 " "

9. From each heat one test ingot shall be cast 2¼ in. x 2¼ in. x 6 in. long. This to be drawn down at one heat by hammering to a test piece ⅞ ins. square by 18 ins. to 20 ins. long. The same when cold to be required to bend to a right angle without breaking. This bar must be bent by blows from a hammer.

10. After cutting off or allowing for the sand on the top end of the ingot, at least 12 ins. more of seemingly solid steel shall be cut off that end of the bloom. If after cutting such length the steel does not look solid, the cutting shall be continued until it does.

11. The inspector representing the purchaser shall have free entry to the works of the manufacturer at all times while his contract is being filled, and shall have all reasonable facilities afforded to satisfy him that the rails are being made in accordance with these specifications. The manufacturer shall furnish daily the carbon determinations of each heat, and a complete chemical analysis of at least one heat of each day and night turn in which each element is to be determined.

12. The requirements for No. 2 rails shall be the same as for No. 1 except that they will be accepted with a flaw in the head not exceeding ¼ in., and a flaw in the flange not exceeding ½ in. in depth.

No. 2 rails to the extent of 5 per cent of the entire order will be received.

Composition.—The composition of steel rails is a much mooted question for the reason that the different processes used in the manufacture of the ore cause the rail to vary in its chemical composition, but do not necessarily change markedly the physical properties of the metal.

Mr. E. W. Richards suggests the following composition after considering the matter from both the point of view of the manufacturer and the user:

	Minimum.	Maximum.
Carbon	.35	.5 of 1 per cent
Silicon	.05	.1 " "
Sulphur	.04	.08 " "
Phosphorus		.08 " "
Manganese	.75	1.00 " "

The American Committee of the International Association for testing materials for rail from 50 lbs. to 75 lbs. per yard gives the following composition:

Carbon	.35 to .50	of 1 per cent
Silicon	Not over .20	" "
Sulphur		
Phosphorus	Not over .10	" "
Manganese	.70 to 1.05	" "

The strength of the rail is affected by the temperature at which it passes through the rolls. It is proposed to introduce into rail specifications that the shrinkage after they leave the finishing roll till they attain normal temperature shall be expressly stated in per cent.

Regarding the wearing qualities of a rail A. J. Moxham states that the life of a rail is now determined by the life of the joint. The question is not how much the rail has worn, but how much has the hammering at the joint destroyed its usefulness. For heavy traffic he states that what is wanted is a hard ductile rail which can only be produced by low phosphorus and high manganese. Anything

RESULTS OF THREE YEARS' TESTS ON RAILS.

(A. J. MOXHAM.)

	Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.	Iron.	Specific Gravity.	Specific Gravity of Iron only.	Breaking Strain. Lbs. per sq. in.	Elastic Limit Tension. Lbs. per sq. in.	Elastic Limit Compression. Lbs. per sq. in.	Wear in ins. per Million cars passing over rails.	Years it will take to run down ½ in. with 11,600 cars passing over rails per day.
Soft rail..	.280	.026	.106	0.066	.790	98.732	7.355	7.956	75.860	45.730	35,000	.00345	25
Hard rail.	.590	.056	.097	.059	.830	98.368	7.841	7.971	118,100	62,500	50,000	.00205	35
Hard and Ductile.	.570	.234	.050	.078	.980	98.088	7.825	7.977	120,380	53,160	47,100	.00488	60

below .10 of 1 per cent phosphorus can only be obtained by greatly increased cost of manufacture equalling practically 8 per cent of the total. The joint wear was not taken into consideration. The service was at the rate of 11,600 cars passing per day.

There is another point in regard to high carbon in a rail, which is, that it is pitted by rain water and is yet too hard to have these pits rolled out by the wheel of the equipment; this increases the rolling friction between the car wheel and rail. The ends of rails also are in some cases ordered to be cut to $\frac{1}{32}$ in. slope, the longest part of the rail being on the head; this will cause the joint at the head of the rail to close first.

The coefficient of expansion of steel may be taken at .0000066 per degree Fahrenheit, and the extreme range of temperature at 120 degs. The change in length of the total range will be .0008 of the length; in a mile this amounts to over 4 ft.

Electrical Resistance of Rails.—There is considerable variation in the determinations of the resistance of steel rails, largely due to the marked effect the percentage of manganese and phosphorus has on the conductivity of steel. A steel rail has a temperature coefficient for resistance of about 0.48 of one per cent for each degree centigrade rise above 20 degs.

The following values have been given for 90-lb. single rail for 1000 ft. in ohms;

Bell	.00666
Goto	.00552
McTigh	.00660
Vail	.00528
Herrick	.00521

For each mile of continuous rail 1 sq. in. section equals approximately 0.24 ohms; then the sectional area of rail divided into this resistance gives the resistance per mile of rail alone.

AREA OF RAILS AND EQUIVALENTS IN COPPER CONDUCTORS FOR TWO TRACKS, FOUR RAILS IN PARALLEL.

Multiply results by two for single track.

Weight of Rails per Yard. Lbs.	Total Sectional Area, Sq. in.	Equivalent in Copper.			Approximate Number 0000, B. W. G.	Resistance per Mile. Rail only. Ohms.
		Sectional Area, sq. in.	Thickness, in.	Width. in.		
50	20	3.33	1	3.33	20	0.0121
60	24	4.00	1	4.00	24	0.0101
70	28	4.66	1	4.66	28	0.0086
80	32	5.33	1	5.33	32	0.0075
90	36	6.00	1	6.00	36	0.0067
100	40	6.66	1	6.66	40	0.0060

Expansion and Contraction of Rails.—Temperature of rail for the year round; flange, 69 degs., head, 70 degs. when the air is 71 degs. in the shade. In a continuous rail it is found from experiment that there was absolutely no movement out of place of the track with the girder type of rail, 6 in. deep, set in concrete, weighing 78 lbs. to the yard; and it was proven that not only the roadbed will hold the track as a complete structure when once imbedded, but that it will hold a rail 10 ft. or 30 ft. as well as one 1100 ft. The expansion in 1100 ft. if not neutralized would be 5¼ ins. It is believed that this expansion is actually due to a minute enlargement and reduction of the sectional area of the rail. A variation of 7 degs. in temperature would subject the rail to a stress of 1000 lbs. per sq.

TABLE OF WEIGHTS AND LENGTHS OF RAILS.

Pounds per Yard.	Gross Tons per Mile.	Feet of Track per Ton of Rails.	Pounds per Yard.	Gross Tons per Mile.	Feet of Track per Ton of Rails.	Pounds per Yard.	Gross Tons per Mile.	Feet of Track per Ton of Rails.
12	18.86	280.0	48	75.43	70.00	84	132.00	40.00
13	20.43	258.46	49	77.00	68.57	85	133.57	39.53
14	22.00	240.00	50	78.57	67.20	86	135.14	39.07
15	23.57	224.00	51	80.14	65.88	87	136.71	38.62
16	25.14	210.0	52	81.71	64.62	88	138.29	38.18
17	26.71	197.65	53	83.29	63.40	89	139.86	37.75
18	28.29	186.67	54	84.86	62.22	90	141.43	37.33
19	29.86	176.84	55	86.43	61.09	91	143.00	36.92
20	31.43	168.0	56	88.00	60.00	92	144.57	36.52
21	33.00	160.00	57	89.57	58.95	93	146.14	36.13
22	34.57	152.72	58	91.14	57.93	94	147.71	35.75
23	36.14	146.09	59	92.71	56.95	95	149.29	35.37
24	37.71	140.00	60	94.29	56.00	96	150.86	35.00
25	39.29	134.4	61	95.86	55.08	97	152.43	34.64
26	40.86	129.23	62	97.43	54.19	98	154.00	34.29
27	42.43	124.44	63	99.00	53.33	99	155.57	33.94
28	44.00	120.00	64	100.57	52.50	100	157.14	33.60
29	45.57	115.86	65	102.14	51.69	101	158.71	33.27
30	47.14	112.0	66	103.71	50.91	102	160.29	32.94
31	48.71	108.39	67	105.29	50.15	103	161.86	32.62
32	50.29	105.00	68	106.86	49.41	104	163.43	32.31
33	51.86	101.82	69	108.43	48.70	105	165.00	32.00
34	53.43	98.82	70	110.00	48.00	106	166.57	31.70
35	55.00	96.0	71	111.57	47.32	107	168.14	31.40
36	56.57	93.33	72	113.14	46.67	108	169.71	31.11
37	58.14	90.81	73	114.71	46.03	109	171.29	30.83
38	59.71	88.42	74	116.29	45.41	110	172.86	30.54
39	61.29	86.15	75	117.86	44.80	111	174.43	30.27
40	62.86	84.0	76	119.43	44.21	112	176.00	30.00
41	64.43	81.95	77	121.00	43.64	113	177.57	29.73
42	66.00	80.00	78	122.57	43.08	114	179.14	29.47
43	67.57	78.14	79	124.14	42.53	115	180.71	29.22
44	69.14	76.36	80	125.71	42.00	116	182.29	28.97
45	70.71	74.67	81	127.29	41.48	117	183.86	28.72
46	72.28	73.04	82	128.86	40.98	118	185.43	28.47
47	73.86	71.49	83	130.43	40.48	119	187.00	28.24
						120	188.57	28.00

in. Taking a track laid at a low temperature of 40 degs., and subject to a maximum of 120 degs. or a variation of 80 degs. the stress is equal to less than 12,000 lbs. per sq. in., much less than the elastic limit. It would therefore appear that the effect on the steel would be harmless.

It is well known to track men that the heavy rails do not show as much expansion and contraction by heat as the lighter sections do. A report was made to the Road Master's Association in 1899 by Mr. V. T. Douglass of the Chesapeake & Ohio R. R., on exposed track construction. He gives the following coefficients for different weights of rails.

Contraction from +5 degrees to —20 degrees F.

Rail.	Coefficient.
56-lb	.00208
75-lb	.00139
85-lb	.00101

Expansion from +5 degrees to +70 degrees F.

Rail.	Coefficient.
56-lb	.00107
75-lb	.00069
85-lb	.00065

A 66-lb. rail, if supported by the proper number of cross ties, will answer every engineering demand, even of high speed electric cars. Anything over this goes to the debt of bad joints.

Rail in use by different companies varied between 2 ins. and 2½ ins. head A large number of roads used ¾ in. to 1 in. wheel flange in width at tread of wheel and ⅝ to ¾ ins. deep.

Useful Formulae For Rails.—The number of tons of rail for one mile single track equals approximately 1⅐ of the weight of rail in pounds per yard; the sectional area of rail in square inches equals approximately $\frac{1}{10}$ of the weight of rail in pounds per yard; the maximum safe weight for rails properly supported on ties is one ton for each 10 lbs. weight of rail per yard.

TIES.

The life of ties is largely affected by the earth in which they are buried, and raising on ballast and drainage increases their life. The life of ties as given by Prof. Roth is as follows:

Black locust, cypress, red cedar	10	years
White oak, chestnut oak, chestnut	8	"
Tamarack	7 to 8	"
Cherry, black walnut, locust	7	"
Elm	6 to 7	"
Long leaf pine	6	"
Red and black oaks	4 to 5	"
Hemlock	4 to 6	"
Spruce	5	"
Ash, beach, maple	4	"

Mr. Hough gives the following table:

Oak	7.4	years
White oak	7.3	"
Post "	7.0	"
Burr "	7.4	"
Rock "	7.0	"
Red "	5.0	"
Chestnut oak	7.1	"
Black oak	4.5	"
Southern pine	6.5	"
White "	6.5	"
Cedar, red	11.8	"
Cedar, white	7.5	"
Cypress	8.7	"

Ash, black	3.8 years.
Ash, white	4.3 "
Cherry	6 to 10 "

The *Railroad Gazette*, Dec. 26, 1884, gives the following percentage of the various woods used upon 90,900 miles out of 121,592 miles in operation of steam track:

White oak	58.2 per cent.
Cedar	10.4 " "
Yellow pine	8.7 " "
Northern pine	6.9 " "
Hemlock	5.9 " "
Chestnut	4 4 " "
Fir	1.7 " "
Spruce	1.6 " "
Cypress	1.0 " "
Miscellaneous soft woods	0.6 " "
Miscellaneous hard woods	0.6 " "
Total	100.0 " "

Climatic conditions play a large part in the depreciation of ties. In low moist country cypress ties last fully as well as cedar; in a dry climate their life is reduced to seven years. Where a tie is covered with earth in its entirety it will decay much more rapidly than where it is only partially covered. It has been noticed that a large percentage of lime in soils will produce premature decay. Yellow pine ties have been found to be preserved by salt used in thawing the snow at guard rails and frogs, while they were badly rotted on adjacent portions of track not salted.

When ties have to be laid on ground, the action of which on the different woods is not known, an examination of fence posts along the route, noting the kind of wood, and obtaining the length of time planted, will suggest the best kinds of woods to use for ties,

There is no economy in putting down cheap ties. The cost of labor alone in ten years will be more than double that of the most durable tie that can be secured. The essential feature of any railway is the permanency of its rail substructure and without good ties this cannot be obtained.

The treatment of ties primarily consists of heating the tie to evaporate the sap out of the cells, and afterwards filling or lining these cells with some compound or chemical which will preserve the mechanical characteristics of the tie, and hermetically seal the cellulose of the tie to protect it from attacks of fungi, or dry or wet rot.

The three principal methods used are Burnettizing, Creosoting and Kyanizing. Burnettizing consists of partially impregnating the wood with zinc chloride. The preparation being soluble loses its value when exposed to rain or water. Oak, pine and fir cannot be thoroughly treated as the preparation only reaches 1½ in. in hard woods, and in soft wood penetrates the sap wood but not the heart of the wood at all.

The Barschall treatment is the Hasselmann method largely used in Germany. Here the cellulose of the wood is chemically acted on during the treating process and forms a direct chemical combination with the woody fiber cellular tissue and cell contents. The treating liquid consists of a combination of sulphates of iron, copper and alumina and kainit (which is a natural salt of sulphate of potash and magnesia and the chloride of magnesia.) This treatment chemically impregnates the whole mass when the timber is boiled in it at a temperature of from 100° cent. to 140° cent., and under a pressure of 15 to 45 lbs.

per square inch and this treatment is said to prevent decay and rot effected on exposure and does not change the physical characteristics of the wood except to reduce its inflammability.

The treatment by creosote or dead oil of tar is largely used, and reports of tests show that the life of ties can be greatly prolonged by such treatment. The cost of treating ties should show a profit over labor of renewals and cost of new ties during the life of the treated tie.

Ties per 1000 ft. and per Mile.

SPACING	PER 1000 FT.	PER MILE
10 ties to 30 ft. rail	333⅓	1,760
11 " " " "	366⅔	1,936
12 " " " "	400	2,112
13 " " " "	433⅓	2,288
14 " " " "	466⅔	2,464
15 " " " "	500	2,640
16 " " " "	533⅓	2,816

CENTER TO CENTER	TIES PER MILE
18 ins.	3,520
21 "	3,017
24 "	2,640
27 "	2,348
30 "	2,113
36 "	1,760

Board Feet, Cubic Feet, and Square Feet of Bearing Surface per Tie.

SIZE	BOARD FEET	CUBIC FEET	BEARING SURFACE
5 ins. x 5 ins. x 7 ft.	14 56	1.213	2.91
5 " x 6 " x 7 "	17.5	1.458	3.5
5 " x 7 " x 7 "	20.41	1.7	4.08
5 " x 8 " x 7 "	23.33	1.944	4.66
6 " x 6 " x 7 "	21.	1.75	3.5
6 " x 7 " x 7 "	24.5	2.041	4.08
6 " x 8 " x 7 "	28.	2.333	4.66
6 " x 9 " x 7 "	31.5	2.625	5.25
6 " x 10 " x 7 "	35.	2.916	5.83
6 " x 8 " x 8 "	32.	2.666	5.33
6 " x 9 " x 8 "	36.	3.00	6.00
6 " x 10 " x 8 "	40.	3.333	6.66

The inspection of ties is largely a matter of experience and judgment. The hewn tie should have flat surfaces. There should be no bark or knot holes or indications of rot. Ties are graded and placed according to traffic, or the rails which they support; the largest and best proportioned ties are used for the joint on main line traffic, the second selection, for general main line work. It is nearly impossible to draw a specification for a tie, as the wood adopted, the location and local timber possibilities to produce good ties and the price advisable to pay, fix the character of tie which it is possible to obtain. The selection of the ties should be in the hands of a competent and skilled inspector.

Steel Ties.—Steel ties have come into use, especially in hot countries where wood is attacked by insects. The steel tie or its equivalent, as shown in the Scranton construction, is becoming more extensively used, as concrete is now largely employed for foundation under roadbeds.

Fig. 92 gives one form of steel tie, which consists of an inverted channel iron 7 ins. wide, 1⅜ ins. web and $\frac{5}{16}$ ins. thick. The rail is secured to the tie by means of an angle bar and bolts. The total weight of tie is about 55 lbs. The spacing of these ties should be arranged from 5 ft. to 11 ft. according to the weight of the rail and the character of sub-construction in concrete work.

Steel ties which rest on ballast are usually provided with concave undersurfaces to prevent ballast from working from under the tie. This character of tie is largely used for steam railroads in southern countries.

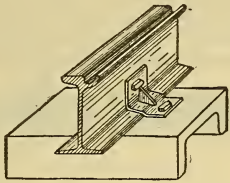


FIG. 92.—STEEL TIE.

Spikes.—The size of the standard spikes for rails from 35 to 40 lbs. is 5 ins. x ½ in.; from 40 to 52 lb. rails, 5 ins. x $\frac{9}{16}$ ins.; from 45 to 85 lb. rails, 5½ ins. x $\frac{9}{16}$ ins.

Spikes Required per 1000 ft. and per Mile Single Track, with Four Spikes per Tie.

SPACING OF TIES	PER 1000 FT.	PER MILE.
10 ties to 30 ft. rail	1333⅓	7,040
11 " " " "	1466⅔	7,744
12 " " " "	1600	8,448
13 " " " "	1733⅓	9,152
12 " " " "	1866⅔	9,856
15 " " " "	2000	10,560
16 " " " "	2133⅓	11,264

SPIKE TABLE.

Size of Spike.	Average Number in 200 lb. Keg.	Weight per Spike.	KEGS PER MILE OF TRACK. Tie Spacing					
			4 Spikes per Tie.			6 Spikes per Tie.		
			2 ft. 6 in.	2 ft. 3 in.	2 ft. 0 in.	2 ft. 6 in.	2 ft. 3 in.	2 ft. 0 in.
3½ in. x $\frac{7}{16}$ in.	900	0.2222	9.39	10.43	11.73	14 08	15.65	17.60
4 in. x $\frac{7}{16}$ in.	780	0.2564	10.83	12.04	13.54	16.24	18.06	20.31
4½ in. x $\frac{7}{16}$ in.	675	0.2963	12.52	13.91	15.64	18.78	20.86	23.46
4 in. x ½ in.	600	0.3333	14.08	15.65	17.60	21.12	23.47	26.40
4½ in. x ½ in.	530	0.3773	15.94	17.71	19.92	23.91	25.56	29.88
5 in. x ½ in.	500	0.4000	16.89	18.78	21.12	25.33	28.17	31.68
5 in. x $\frac{9}{16}$ in.	390	0.5128	21.66	24.07	27.08	32.50	36.10	40.61
5½ in. x $\frac{9}{16}$ in.	350	0.5714	24.14	26.82	30.17	36.21	40.23	45.25

It has been found that it takes 4281 lbs. to draw a $\frac{9}{16}$-in. spike driven 4¼ ins. into a seasoned oak tie; the same spike in unseasoned oak took 6523 lbs. On seasoning the wood the spike loses in holding power. Experiments on ½-in. spikes driven 4½ ins. into yellow pine, showed 3000 lbs. and for oak, 6000 lbs. The force is considerably more in hard wood to pull the spike out; in softer woods the force is about $\frac{1}{8}$ less to pull the spike than that required to drive it.

Tie Rods.—These take all lengths and sizes depending upon the service and gage of road. The form generally adopted is shown in Fig. 93, ⅜ ins. x 1½ ins. being

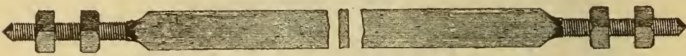


FIG. 93.—TIE ROD.

a section of iron commonly used. The thread should be cut far enough back so the tie rod can be inserted after the rails are in place, and the hole in the rail should be large enough so as not to mar the thread in passing the tie rod in. The flat section requires very little space between the blocks in brick or granite pavement, but the tie rods shonld be so spaced that they can accomodate between them a convenient number of paving blocks or bricks without loss of time in cutting the pavement to fit. Round rods are used in macadam construction.

Tie Plates.—The tie plate is more generally used on elevated than on surface roads and is interposed between the base of the rail and tie so as to present a larger surface to the tie than the base of the rail, Fig. 94; it is usually secured independently to the tie so the rail movement will not chafe and wear the tie at the point of bearing with the rail. On curves tie plates have an additional advantage of distributing the canting effect and lateral strain on the rail over a large area, and, in addition, where the spike passes through the tie plate the efficiency of the spike is increased, preventing the movement of rail away from gage line.

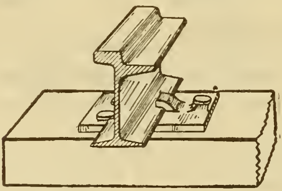
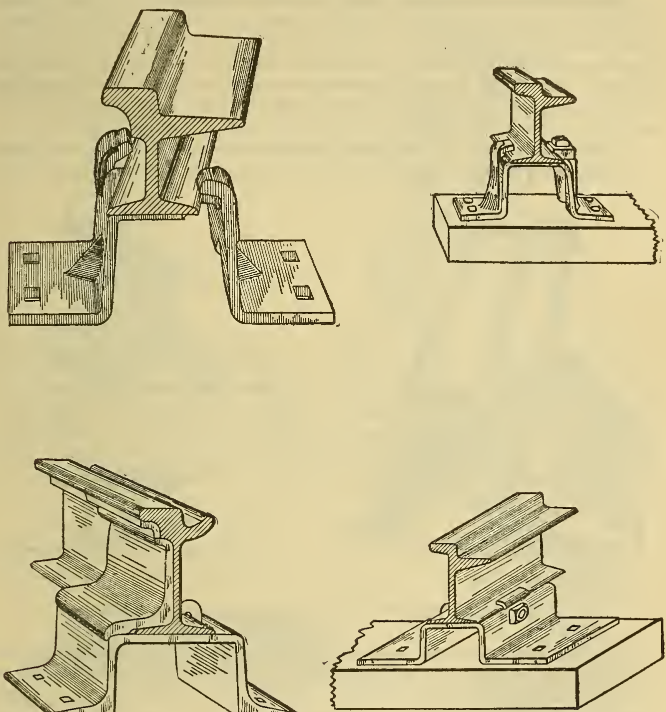


FIG. 94.—TIE PLATE.

FIG. 95.—OLD HORSE-CAR RAIL ON STRINGER.

Chairs.—In horse railways, the flat rails employed were mounted on wooden stringers. This was necessary to raise the rail above the tie and thus provide room for paving and sufficient filling under the pavement to prevent unequal settling due to the pavement bearing directly on the tie. This construction is shown in Fig. 95. With the low rails first used in electric railway work chairs were used to supplant this wooden stringer, as it gave trouble from rapid decay, especially under the joints. They were originally of cast iron, but on account of the variation in castings their fitting to the rail section was not satisfactory, and the fragile character of the chair led to the introduction of chairs made of drop forgings of iron and steel in various forms, Figs. 96, 97, 98 and 99, taking the form of the box girder rail to which is fastened the base of the rail by bolts or clips as shown. To overcome the canting effort of the rail on the passing of a load, chairs combined with braces were used, see Figs. 100, 101 and 102. These also



FIGS. 96, 97, 98 AND 99.—RAIL CHAIRS.

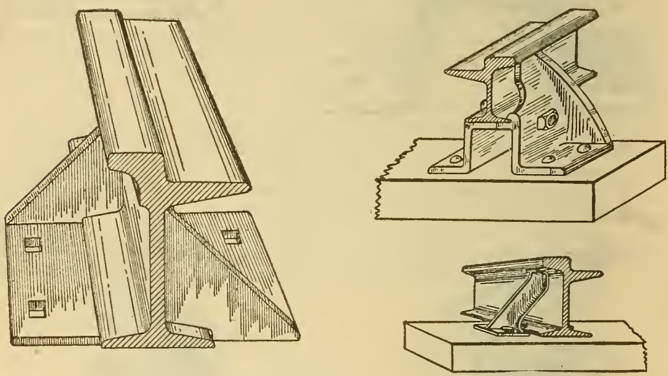
transfer directly to the tie the side thrust caused by the car wheel flanges bearing against the side of the rail.

RAIL JOINT FASTENERS.

In no part of the track has more thought or ingenuity been spent than on the proper mechanical joining of the rail lengths together. The ideal joint is one which is as strong and substantial as the rail itself. If an opening is left between the ends of the rails, say of ⅛ in., to accomodate the changes in the length of the rail due to differences in temperature, an opportunity is afforded to start a pound when the wheels pass over it; each wheel in passing contributing its quota toward the destruction of the joint.

Bolted joints take the form of a plate bearing against the side of the rail and bridging the joint. The common form consists of an arched plate having a top and bottom bearing rolled to fit the rail, and secured in position by bolts passing through the joint plate and rail. Figs. 81 to 91 show sections giving some different forms of joint plates. For rails 6 ins. and over in height the bolts can be drawn so as to buckle the joint plate thereby destroying its bearing contact with the rail. Figs. 82, 83, 84 and 85 show an intermediate rib rolled in the joint plate which is normally out of contact with the web of the rail, but is brought to bear on the web before the bolts are tightened sufficiently to buckle the plate.

Pratt & Alden give the following recommendations regarding joint plates: "For 6-in. rails they should not be less than $\frac{9}{16}$ ins. thick at the center; for 7-in.



FIGS. 100, 101 AND 102.—RAIL CHAIRS AND BRACES.

rails $\frac{5}{8}$ ins., and for 9-in. rail not less than $\frac{7}{8}$ ins., to prevent buckling under the bolt pressure." They advise a double row of bolts located as near the bearing surface as possible for the reason that the channel or joint plate as shown depends entirely on the compression given them against the rail. Several railroads have hot riveted the plate to the rails, instead of using track bolts.

To strengthen this weak part of the track numerous track joints have been devised to afford a bearing to the rails independently of the track bolt tension. The lengthened chair at the joint was the first attempt in this direction for improving the joint.

The "Continuous" rail joint shown in Fig. 103 is an extension of the joint plate, which includes the bearing of the base of the rail on the plate; here tension and compression are set up within the joint plate, and do not act directly against the bolt heads. If the fit was perfect around the lower flange of the rail it could transfer the strains across the joint without movement of the rail head. Fig. 104 shows the "Churchill" rail joint, which provides a bearing for the rail on a plate secured between the projecting sides of the joint plate, the lower bolt acting as a locking device for this bearing plate. The Atlas joint shown in Fig.105 embraces the joint with two pieces which are clamped together by bolts, and extra metal is used where the joint is suspended. Fig. 106 shows the Weber rail joint which consists of an L-iron, on which rests the rail base, and is secured to the rail joint by lengthening the track bolts to pass through the angle, as well as through a wood filter interposed between the regular joint plate and the angle.

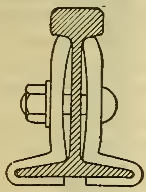


FIG. 103.—CONTINUOUS RAIL JOINT.

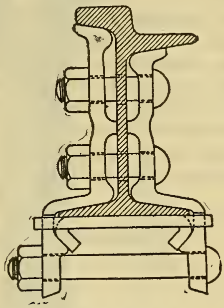


FIG. 104.—CHURCHILL RAIL JOINT.

There are a number of track joints of the bolted and keyed type, some of which should give good service. But the track joint question is one that every railway man has to study for himself in order that the conditions of his own special problem of tracks can be fully considered. The spacing of the bolts and the length of the joint plate are matters on which there is a diversity of opinion,

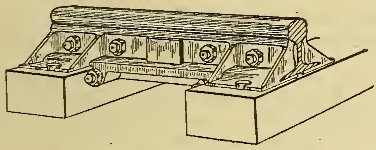


FIG. 105.—ATLAS RAIL JOINT.

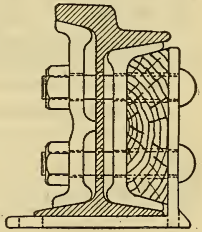


FIG. 106.—WEBER RAIL JOINT.

and are governed largely by local conditions. Track joints vary in length from 20 ins. to 38 ins., and are fitted with from four to twelve bolts

Electrically Welded Joints.—In the original method of electrically welding joints the adjacent rail ends were abutted and a current of about 20,000 amps. was passed through the joint. This heating effect brought the contact surfaces up to welding temperature and while at this temperature the rail ends were forced together and welded. The heating of the rails evidently reduced the carbon in the steel for the rail was softened and when the contraction took place due to air temperature changes, the rail fractured at the points of welding in a number of cases, and the rail being softer at these portions low spots also developed. The latest method is to electrically weld on each side of the joint bars with bosses which confine the heat to small areas. The results are said to be very satisfactory and a large amount of track welded in this way is in use in Buffalo.

Cast Welded Joints.—In this case the joint is surrounded by a matrix to hold molten iron in such form that when the mass is cooled the additional strength afforded by the metal surrounding the joint compensates for the loss in strength of the rail due to its rise in temperature. These joints are poured weighing from 120 lbs. to 250 lbs. each and have given good results in service.

For the electrical connection of the rail joint, see "Return Circuit."

Bolts.—Bolts for plain channel joint plates should be ⅞ ins. in diameter with ribbed plates. Bolts may be 1 in. in diameter. The nut may be either square or hex-

WEIGHTS OF STANDARD TRACK BOLTS.

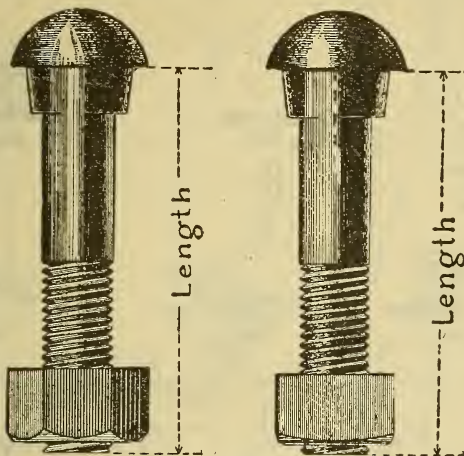
Bolts with Square Nuts. Pounds per Thousand.

Diam. inches.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.	3¼ in.	3½ in.	3¾ in.	4 in.	4¼ in.	4½ in.	4¾ in.	5 in.	Diam. inches.	Weight of 1000 Nuts.
½	260	274	288	302	316	330	344	358	372	386	400	414	428	½	112
9/16	352	370	388	406	424	442	460	478	496	514	532	550	568	9/16	146
⅝	454	476	498	520	542	564	586	608	630	652	674	696	718	⅝	218
¾	626	658	690	722	754	786	818	850	882	914	946	978	1,010	¾	245
⅞	858	901	944	987	1,030	1,073	1,116	1,159	1,202	1,245	1,288	1,331	1,374	⅞	374
1	1,155	1,210	1,265	1,320	1,375	1,430	1,485	1,540	1,595	1,650	1,705	1,760	1,815	1	525
1⅛	1,595	1,666	1,737	1,808	1,879	1,950	2,021	2,092	2,163	2,234	2,305	2,376	2,447	1⅛	747

Bolts with Hexagon Nuts. Pounds per Thousand.

Diam. inches.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.	3¼ in.	3½ in.	3¾ in.	4 in.	4¼ in.	4½ in.	4¾ in.	5 in.	Diam. inches.	Weight of 1000 Nuts.
½	253	267	281	295	309	323	337	351	365	379	393	407	421	½	93
9/16	327	345	363	381	399	417	435	453	471	489	507	525	543	9/16	122
⅝	436	458	480	502	524	546	568	590	612	634	656	678	700	⅝	182
¾	597	629	661	693	725	757	789	821	853	885	917	949	981	¾	216
⅞	822	865	908	951	994	1,037	1,080	1,123	1,166	1,209	1,252	1,295	1,338	⅞	316
1	1,087	1,132	1,187	1,242	1,297	1,352	1.407	1.462	1,517	1,572	1,627	1,682	1.737	1	462
1⅛	1,513	1,584	1,655	1,726	1,797	1,868	1,939	2,010	2,081	2,152	2,223	2,294	2,365	1⅛	685

agon, the square nut giving the largest surface against the joint plate, but in many cases the hexagon has to be used in order to obtain clearance. The portion of the bolt adjacent to the head for a length equals the thickness of the joint plate. It is oval in form and fits into an oval hole punched in the joint plate. See Figs. 107 and 108.



FIGS. 107 AND 108.—TRACK BOLTS.

SPECIAL WORK.

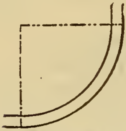
This term is used to cover all portions of track requiring any special designing, such as curves which cannot be sprung into place by the track foreman, crossings, turnouts, switches, etc.

A plain curve, Fig. 109, connects two straight sections of track at an angle to each other, both of the straight sections being tangent to the connecting curve. Fig. 110 shows the reverse curve which connects two tangent sections of track parallel to each other. Fig. 111 shows the right hand crossover, Fig. 112, the left hand crossover. Figs. 113 and 114 gives the right and left hand branch-offs respectively. Fig. 115 shows the crossing and Fig. 116, the connecting curve and crossing. Fig. 117 shows the plain Y; Fig. 118, the three-part Y and Fig. 119, the three-part through Y.

Turnouts, Switches, Etc.—Turnouts are illustrated in Figs. 120 to 122. The diamond turnout, where the main track is central to both turnout tracks is given in Fig. 120. Fig. 121 shows the side turnout where the turnout is thrown over to the side of the main line, and Fig. 122 shows the turnout where the center of the main line track is displaced by the distance between the centers of the turnout tracks.

In Fig. 123 the names of the different parts of special work as they are generally known are given, although their nomenclature varies in detail in different parts of the country. The point of crossing of two rails is commonly known as a frog. The initials of the different parts are generally used: e. g., L. H. T. S. for left-hand tongue switch, etc.

Where special work is ordered the parts that are shown in Fig. 123 together are generally made in one piece. The "hand" is always determined by the side to which the curve turns off as it appears to a person facing the point of the curve.



PLAIN CURVE.

FIG. 109.

REVERSE CURVE.

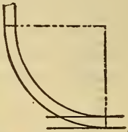
FIG. 110.

RIGHT HAND CROSS-OVER.

FIG. 111.

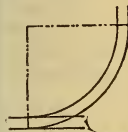
LEFT HAND CROSS-OVER.

FIG. 112.



RIGHT HAND BRANCH-OFF.

FIG. 113.

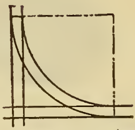


LEFT HAND BRANCH-OFF.

FIG. 114.

CROSSING.

FIG. 115.

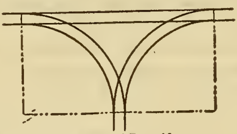


CONNECTING CURVE AND CROSSING.

FIG. 116.

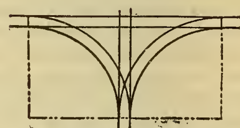
PLAIN Y.

FIG. 117.



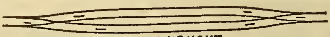
THREE PART Y.

FIG. 118.



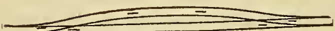
THREE-PART THROUGH Y.

FIG. 119.



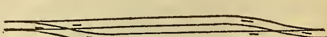
DIAMOND TURNOUT.

FIG. 120.



SIDE TURNOUT.

FIG. 121.



THROWN OVER TURNOUT.

FIG. 122.

The method of construction of special work varies with its uses. Bolted work is largely used in exposed surface track, but in city streets a more permanent structure has to be used in order that the life will be longer, on account of

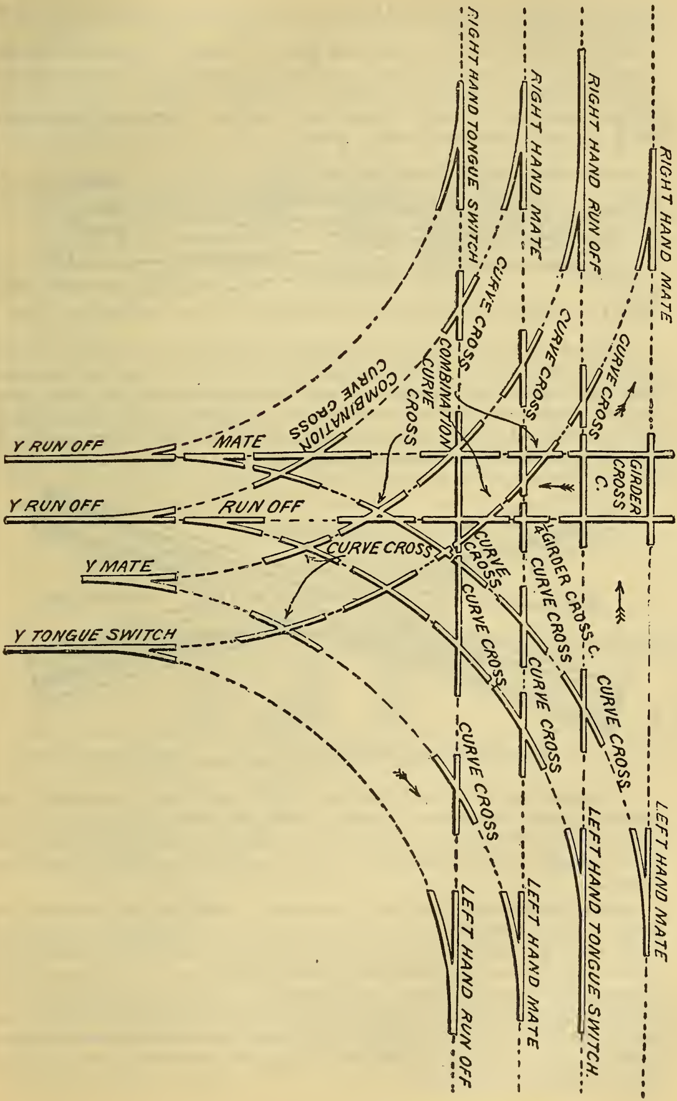


FIG. 123.—NOMENCLATURE OF SPECIAL WORK.

the large expense of repaving and renewal. Here the rail parts are cast together after being fitted.

Fig. 124 shows one of the methods used for built-up frog work, and the nomenclature of the different parts. The fitting of pieces of rail together is done by using a templet to obtain the proper track angle between the rails and making a pattern which fits between the heel and flangeway. These patterns are then cast in iron and bolted and riveted in position.

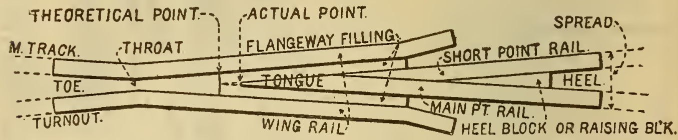


FIG. 124.—BUILT-UP FROG WORK AND NOMENCLATURE OF DIFFERENT PARTS.

The wear on special work occurs at the switch and mate points and frog crossings. In order to maintain these points and have the flange of the wheel ride so that the tread of the wheel will not bruise the switch or frog points, they are made of harder metal than the main part of the special track. This result is generally obtained by an inset of manganese, or nickel, steel, formed to fit as in Fig. 125, or by some special hardening process.

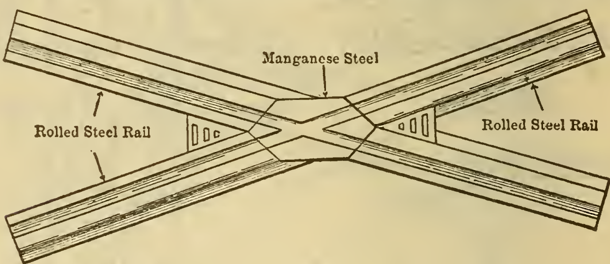


FIG. 125.—SPECIAL WORK WITH HARDENED POINTS.

The spring frog, Fig. 126, is used on the main line where it is normally continuous; at track crossings angle plates are used, as shown in Fig. 127, in built-up frogs, which are bolted or riveted to the intersecting rails. In addition a sole plate is usually bolted underneath the track crossings to maintain the alignment of rails.

Guard Rails.—At curves there is required a guard for the outside of the flange of the outside wheel on the curve for curves of radius of 300 ft. and under. It is the practice for curves under 70 ft. radius to have guards on both rails for both wheels. The distance to space a guard depends upon the depth and thickness of the car wheel flange, and whether the curve is laid wider than gage or natural gage. In some track construction the curve is laid to a slightly narrower gage than the main track gage for the reason that the gage line is a radius of the curve while the wheel axles are at an angle to this radius, making their gage line across rails shorter.

In relation to curved rails the clearance between guard and rail can be determined by making a section of the wheel flange tangent to the wheel tread in celluloid and passing this around the gage line of the curved rail; allowing the

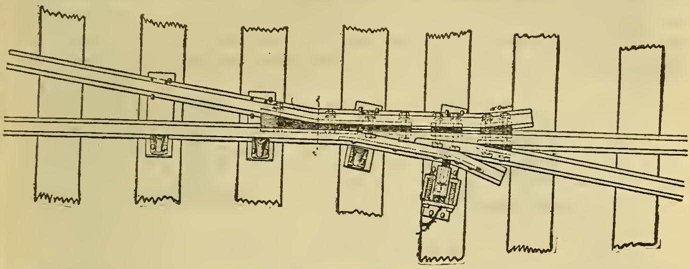


FIG. 126.—SPRING FROG (MAIN LINE).

guard rail to clear this at least one-quarter of an inch will give the proper spacing between the guard and the rail.

Fig. 128 shows one method to be used on long radius curves where a cast iron spacing piece and strap iron guard is bolted to the rail. The spacing pieces are from 14 ins. to 24 ins. on centers depending upon the curvature of rails. Figs. 129, 130 and 131 show other approved forms.

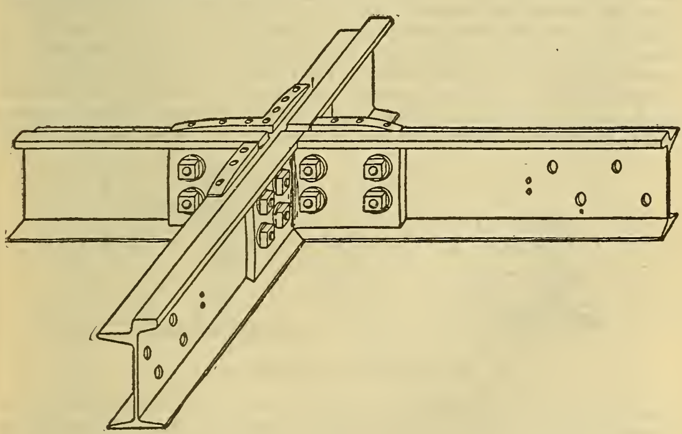
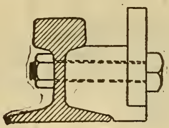
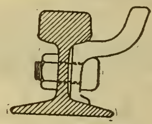


FIG. 127.—BUILT-UP FROG.

Where tracks cross trestle work and at dangerous crossings it is compulsory in some states (and also an advisable construction) to place two continuous guard rails between the rails, bent to nearly reach each other ten feet before approaching the hazardous crossing, in order to throw a derailed car toward the track.

Curves.—Where the track changes its direction the introduction of a curve is necessitated. The center line of this curve may be struck joining the tangents, the radius being determined by the local conditions. In single track, in streets, the center from which the curve is struck may be in the curb. Sufficient clearance must be allowed for the obstructions at street corners so as not to endanger alighting passengers, or, in the case of open cars, passengers standing on the

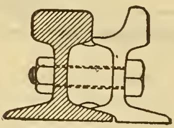


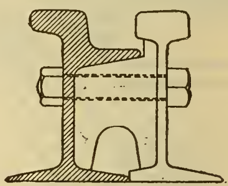


FIGS. 128 AND 129.—GUARD RAILS.

running board. An accident arising from such a condition is evidence in itself of improper construction, and renders the railway company liable for injuries sustained.

The surface of a street presents obstructions in the way of manholes, and subsurface structures belonging to other companies. If none of these exists the diagram given on page 123 of curves for 90 degs. when main line tangents are at right angles, can be used in the following way: Required to find from the tangents the largest radius possible for the track; suppose that the road passes from one intersecting street 50 ft. wide to another 30 ft. wide at right angles to each other, this will bring the center line of track 25 ft. from one curb and 15 ft. from the other curb. From one scale terminating at *A* on the diagram page 123 follow the line from 25 until it meets the line from the other scale terminating at *A* from 15; these will be found to intersect near the curve 60 which gives the radius of the largest curve that can be used under these conditions. Plotting these results on section paper shows, *M*, Fig. 132, that the dotted center line just strikes





FIGS. 130 AND 131.—GUARD RAILS.

the curb line. The radius of the proper curve must be reduced by such an amount that the center of the track will be so far away from the corner of the curb that the widest car will pass with sufficient clearance. The car body forms a portion of a moving polygon, the side of which is permanently fixed through the centers of the car axles in a single truck, and through the truck pivots in a double truck car. All car body movements due to play in trucks tend to throw the car body away from its shortest curve of motion.

The usual way that this proper curve is located graphically is to cut out of translucent celluloid the horizontal projection of the outline of the car body on the

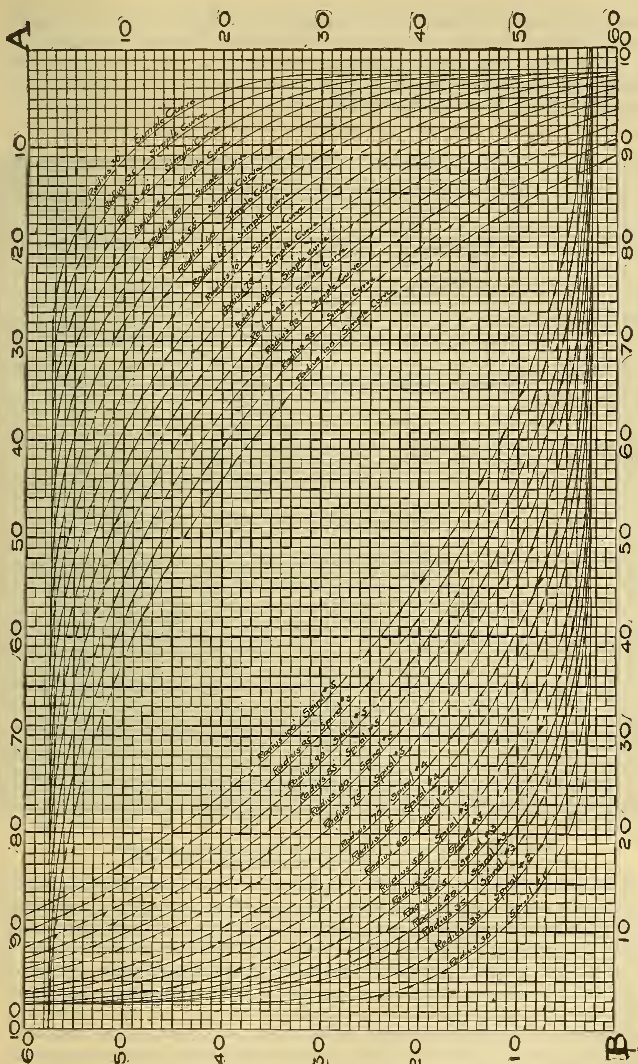


CHART FOR LOCATING CURVES.

same scale as is used for the special work layout, and through the fixed center of axles or trucks as the case may be drill a small hole. With this templet the position of nearest approach can be found, and it will also locate the points through which the truck centers must pass for the largest available curves. Thus, with fixed tangent positions, the two points which represent the truck centers will locate the simple curve to be used for each case.

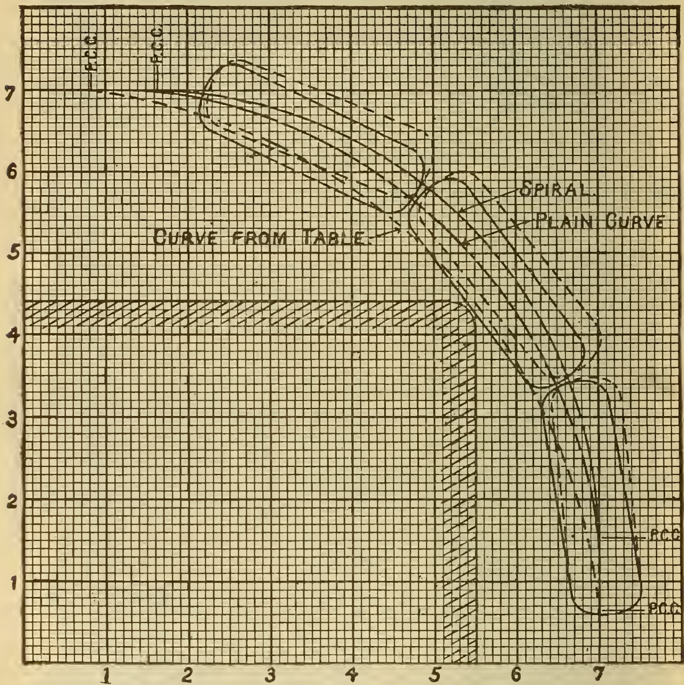


FIG. 132.—GRAPHIC METHOD OF LAYING OUT CURVES.

If there are any obstructions, such as poles, lamp posts, or water plugs along the curb, allowance should be made for clearance when passengers are standing on the running board or step of car. For economical reasons the tendency is to increase the length and width of the car body. It is therefore important that the best possible compromise should be made between the longest curve radius that can be used and the maximum clearance, many roads to day being compelled to change curves in order to operate larger cars.

In the consideration of curves on double track, each track can be treated independently, but as in this case the car on the other track is the obstruction to be cleared, the car fender has to be considered as part of the car, as well as the movement of the carbody on its bearings due to centrifugal force which will displace the inside car toward the outside one in passing. Two templets should be used and in no position of either should there be less than the allowed safe clearance, which varies with the speed and radius of curves.

The curves in Fig. 132 have been worked out for 28 ft., single over all, car bodies having trucks 7 ft. between wheel centers, to show the method of application. In many cases this curve has again to be shifted to avoid obstructions

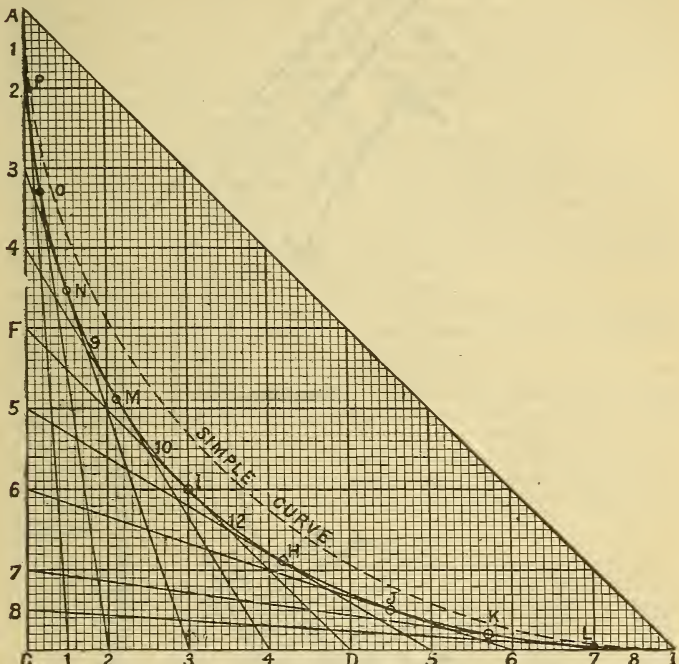


FIG. 133.—METHOD OF LAYING OUT EASEMENT CURVE.

which cannot be moved, such as gate boxes, man hole covers, etc., all of which are difficulties which confront the railway engineer at many curve locations.

The simple curve only has so far been considered, but the ones really laid down in modern railway practice are what are variously known as spiral, transition and easement curves. These are compound curves which change their direction near the tangent less rapidly than the simple circle. They are composed of a number of curves with varying radii, the longer radii being at the switch point and gradually reducing in length until the central portion of the curve becomes a plain circle. The effect of a car passing around one of these compounded curves is to gradually increase the angular motion of the car around the curve so as to make the change in direction less perceptible.

An easement curve of the form of a parabola can be laid out on the ground in the following manner: Continue the track tangents to their point of intersection,

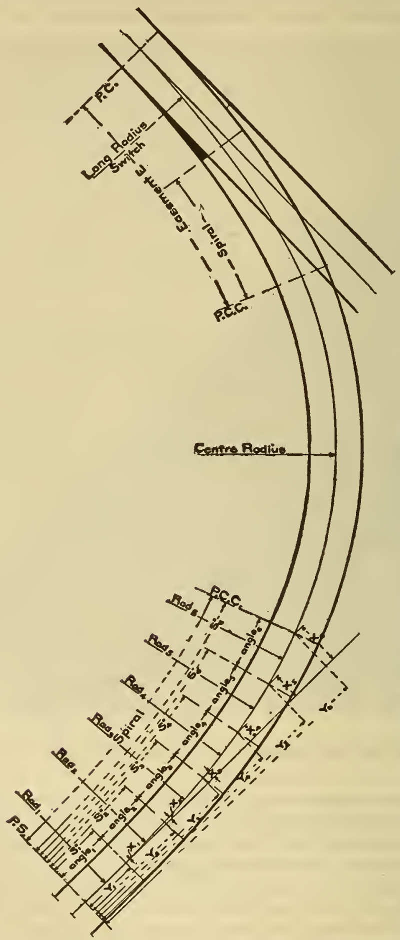


FIG. 134.—METHOD OF LAYING OUT CENTER LINE OF TANGENTS.

and at the point, which will allow of the clearances in the center of the curve, drive a stake in a symmetrical curve, at the point marked *I* in Fig. 133, which will be at equal distances from the point where the track center leaves the tangent. Having located these points, marked *A* and *B*, by driving stakes, stretch a string (⅛ in. cotton cord will do) between *C* and *B* and *C* and *A* which will form the track tangents; then between these two lines stretch a cord and carry it toward *A* and *B* from *C* until it touches the stake *I*. This cord should be secured to stakes *F* and *D* both located the same distance from *C*, when the cord is touching stake *I*.

To locate the other points in the curve, divide distances *C–F*, *C–D* into an equal number of parts and also *F–A* and *D–B*, numbering the divisions from *A* to *C* in order and from *C* to *B* in the same order. Stakes should be driven at each of the points and cords should be drawn for stakes of like number on the two tangents, when the points on these curves will be at the center of any cord between two adjacent intersecting cords: e. g. *I* is located midway between 10 and 12, *M* is located midway between 9 and 10, etc.

When work is ordered for curves of this character, the points *A*, *B*, *C*, *D*, *F* and *I* should be plotted, as these points will determine the form of the curve from which the rail manufacturers can bend the rail. The dotted line shows the departure of this curve from the plain circle connecting the two tangents. This curve presents difficulties in double tracks, but curves derived from a succession of decreasing arc lengths from the point of tangency of the track until a simple curve can be struck, and again becoming a symmetrical spiral until the other tangent track is reached, give better center clearances.

Fig. 134 gives the method of laying out; the center line of track tangents are laid out, and from them are computed the displacement of the track from this line for the different radii of curves forming this spiral.

Supposing that spiral No. 1 was required to fit between two track tangents at right angles to each other, the first curve would have a radius of 210 ft., and would include an arc of 42 minutes, as shown in the table under the heading "angle." The center line would depart .015 ft. from the center line, column "*x*," and this point would be 2.565 ft. from the point of starting. These points can be measured off for each point of departure along *X* and *Y* as shown in Fig. 134.

The column headed "S°" gives the total angular deflection at each point of the spiral.

SPIRAL NO. 1.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	210	0° 42′	0.015	2.565	0° 42′	.00007	.01222
2	105	1° 24′	0.078	5.130	2° 06′	.00067	.03664
3	70	2° 6′	0.219	7.692	4° 12′	.00269	.07324
4	52½	2° 48′	0.469	10.245	7° 0′	.00745	.12187
5	42	3° 30′	0.860	12.780	10° 30′	.01675	.18224
6	35	4° 12′	1.420	15.283	14° 42′	.03273	.25376

SPIRAL NO. 2.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	300	0° 30′	0.011	2.618	0° 30′	.00004	.00873
2	150	1° 00′	0.057	5.235	1° 30′	.00034	.02618
3	100	1° 30′	0.160	7.851	3° 0′	.00137	.05234
4	75	2° 00′	0.342	10.463	5° 0′	.00381	.08716
5	60	2° 30′	0.627	13.065	7° 30′	.00856	.13053
6	50	3° 00′	1.036	15.651	10° 30′	.01675	.18224
7	42½	3° 30′	1.587	18.187	14° 0′	.02970	.24192
8	37½	4° 00′	2.309	20.703	18° 0′	.04894	.30902

SPIRAL NO. 3.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	300	1° 0′	0.046	5.236	1° 0′	.00015	.01745
2	150	2° 0′	0.229	10.468	3° 0′	.00137	.05234
3	100	3° 0′	0.639	15.688	6° 0′	.00548	.10453
4	75	4° 0′	1.368	20.871	10° 0′	.01519	.17365
5	60	5° 0′	2.501	25.982	15° 0′	.03407	.25882
6	50	6° 0′	4.118	30.959	21° 0′	.06642	.35837
7	40	7° 0′	6.143	35.403	28° 0′	.11705	.46947

SPIRAL NO. 4.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	420	0° 42′	0.031	5.131	0° 42′	.00007	.01222
2	210	1° 24′	0.157	10.261	2° 06′	.00067	.03664
3	140	2° 6′	0.439	15.384	4° 12′	.00269	.07324
4	105	2° 48′	0.939	20.490	7° 0′	.00745	.12187
5	84	3° 30′	1.720	25.561	10° 30′	.01675	.18224
6	70	4° 12′	2.839	30.567	14° 42′	.03273	.25376
7	60	4° 54′	4.352	35.469	19° 36′	.05794	.33545

SPIRAL NO. 5.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	600	0° 30′	0.023	5.236	0° 30′	.00004	.00873
2	300	1° 0′	0.114	10.471	1° 30′	.00034	.02618
3	200	1° 30′	0.320	15.703	3° 0′	.00137	.05234
4	150	2° 0′	0.685	20.926	5° 0′	.00381	.08716
5	120	2° 30′	1.255	26.130	7° 30′	.00856	.13053
6	100	3° 0′	2.073	31.302	10° 30′	.01675	.18224
7	85	3° 30′	3.175	36.374	14° 0′	.02970	.24192

SPIRAL NO. 6.

	Rad.	Angle.	*x*.	*y*.	S°.	Ver. Sine.	Sine.
1	900	0° 20′	0.015	5.236	0° 20′	.00002	.00582
2	450	0° 40′	0.076	10.472	1° 0′	.00015	.01745
3	300	1° 0′	0.213	15.706	2° 0′	.00061	.03490
4	225	1° 20′	0.457	20.936	3° 20′	.00169	.05814
5	180	1° 40′	0.837	26.158	5° 0′	.00381	.08716
6	150	2° 0′	1.385	31.365	7° 0′	.00745	.12187
7	128	2° 20′	2.125	36.524	9° 20′	.01324	.16218

Where a switch is to be located at the beginning of a curve the radius of the switch tongue limits the first radius to be used, and the easement cannot be as great as in plain track, 100 ft. being a common radius for switch points.

The Union Traction Co., Philadelphia, has developed for its own work spirals for 90 deg. curves which fit its track gage, 5 ft. 2¼ ins. The company always take these measurements from the gage line of the inner rail, the first easement radius being greater than the above tables, and the center radius less, which gives greater clearance between cars at center of the curve. Fig. 135 and table on page 129 give data of the standard plain curve. Fig. 136 and the table give curves with 100 ft. radius switch. Fig. 137 gives the combination of these two curves in the standard branch-off curves.

It is not within the scope of a handbook to go into the details of the treatment of complicated cases of spirals and curves. The matter can be found treated fully in Pratt & Alden's "Street Railway Roadbed," Tratman's "Railway Track and Track Work," Searle's "Field Engineering," and many articles on special work in the *Street Railway Journal.*

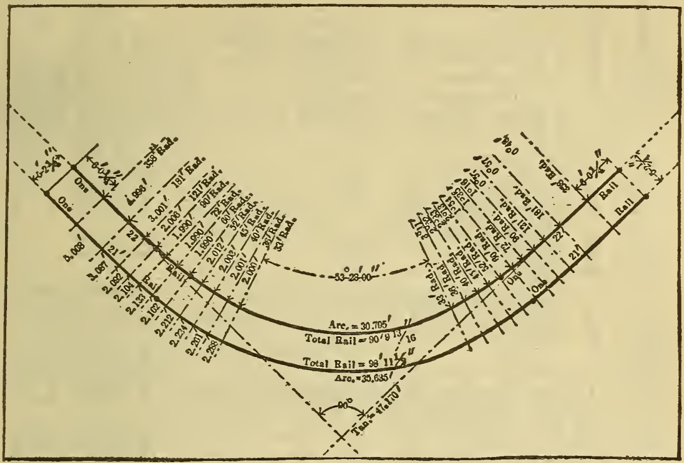


FIG. 135.—STANDARD PLAN CURVE.

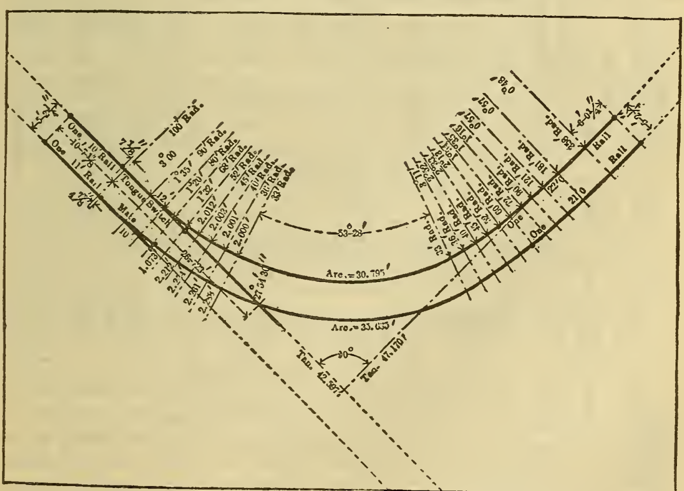


FIG. 136.—EASEMENT FOR BRANCH-OFF CURVE WITH SWITCH.

U. T. CO.

ELEMENTS OF NEW 90° CURVE.

	R.	Deflec.	Total Deflec.	Curve. Abs.	Curve. Ord.	Centers. Abs.	Centers. Ord.	Length of Arc. Inside.	Length of Arc. Outside	Tan.	Ex. Sec.
PLAIN.	358	0°–48′	0–48	4.998	.035	0.000	358.000	4.996	5.068	Middle R	in 1st col.
	181	0 -57	1–45	7.999	.101	2.471	181.017	3.001	3.087	For Switch R < 60 +	Same for Switch if
	121	0 -57	2–42	10.003	.179	4.304	121.045	2.006	2.092	Sub. 4.573	R < 60 +
	90	1 -16	3–58	11.990	.295	5.764	90.080	1.990	2.104	95.844	37.391
	72	1 -25	5–33	13.972	.460	7.009	72.123	1.990	2.133	79.132	29.997
	60	1 -54	7–27	15.949	.685	8.170	60.179	1.990	2.162	68.349	25.106
	52	2 -13	9–40	17.938	.985	9.207	52.246	2.012	2.212	61.453	21.888
	45	2 -33	12-13	19.905	1.365	10.382	45.346	2.003	2.234	55.728	19.129
	40	2 -52	15–05	21.849	1.837	11.440	40.459	2.001	2.261	51.899	17.218
	36	3 -11	18–16	23.765	2.411	12.481	36.597	2.000	2.288	49.078	15.756
	33	53 -28	71–44	44.759	23.404	13.422	33.748	30.795	35.635	47.170	14.727
										Frog.	
										Angle.	Lead
SWITCH.	100	3 -00	3–00	5.234	.137	0 000	100 000	5 236	5 508	20°-00′-33″	20 471
	90	1 -35	4–35	7.715	.301	0 523	90 014	2 487	2 630	21 -28 -07	29 346
	80	1 -20	5–55	9.569	.472	1 322	80 046	1 862	1 982	23 -59 -49	27 892
	68	1 -32	7–27	11.376	.684	2 559	68 110	1 820	1 959	25 -22 -45	27 320
	52	2 -13	9–40	13.366	.983	4 634	52 245	2 012	2 212	26 -27 -01	26 995
	45	2 -33	12-13	15.332	1.363	5 809	45 344	2 003	2 234	27 -18 -52	26 808
	40	2 -52	15-05	17.276	1.835	6 867	40 457	2 001	2 261	27 -54 -30	26 723
	36	3 -11	18-16	19.192	2.409	7 908	36 595	2 000	2 288		
	33	53 -28	71-44	40.186	23.403	8 849	33 746	30 795	25 635		

For any Curve

$Tan_1 = x_1 y_2 \operatorname{cosec} \Delta - y_1 \operatorname{cotan} \Delta$. $Tan_2 = x_2 + y_1 \operatorname{cosec} \Delta - y_2 \operatorname{cotan} \Delta$.

$Tan_1 = R_1 \sin a_1 + R_2 [\sin (a_1 + a_2) - \sin a_1] + R_3 [\sin (a_1 + a_2 + a_3 - \sin (a_1 + a_2)]$ &c.$- Tan_2 \cos \Delta$.

$Tan_2 = \{ R_1 \operatorname{vs} a_1 + R_2 [\operatorname{vs} (a_1 + a_2) - \operatorname{vs} a_1] + R_3 [\operatorname{vs} (a_1 + a_2 + a_3) - \operatorname{vs} (a_1 + a_2)]$ &c. $\} \operatorname{cosec} \Delta$.

R	From	To	Tangent 90°	Abs. of Middle Center.	Ord. of Middle Center
PLAIN.	33	36	.63617 R + 26.176	31344 (36—R) + 12 481	36 597— 94961 (36—R)
	36	40	.70532 R + 23.686	26022 (40—R) + 11 440	40 459— 96555 (40—R)
	40	45	.76574 R + 21.270	21161 (45—R) + 10 382	45 346— 97735 (45—R)
	45	52	.81788 R + 18.923	16792 (52—R) + 9 207	52 246— 98580 (52—R)
	52	60	.86190 R + 16.635	12966 (60—R) + 8 170	60 179— 99156 (60—R)
Sw.	52	68	.86190 R + 12.060	12966 (68—R) + 2 559	68 110— 99156 (68—R)
	68	80	.89159 R + 10.041	10308 (80—R) + 1 322	80 046— 99467 (80—R)

Formulæ.

For symmetrical 90° curve;
Tan = R (cos s — sin s) + Abs. S + Ord. S
For symmetrical curve, any angle;
Tan = Ct. Abs. + Ord. × tan ½ Δ
Ex. Sec. = Ct. Ord. × sec. ½ Δ — R

$$= \frac{\text{Ct. Ord.}}{\cos \frac{1}{2} \Delta} - R$$

S = end of spiral approach. s = Δ at S

MIDDLE ORDINATES ON TEN FOOT CHORDS.

M. O.	Radius.		M. O.	Radius.		M. O.	Radius.		M. O.	Radius.	
	ft.	in.		ft.	in.		ft.	in.		ft.	in.
1/2	300	1/4	2 5/16	64	11 9/16	3 9/16	42	3 1/16	4 13/16	31	4 3/8
9/16	266	8 1/16	2 11/32	64	1 3/16	3 19/32	41	10 11/16	4 27/32	31	2 1/16
5/8	240	7/16	2 3/8	63	3 1/16	3 5/8	41	6 3/8	4 7/8	30	11 5/8
11/16	218	1 13/16	2 13/32	62	5 13/32	3 21/32	41	2 1/8	4 29/32	30	9 5/16
3/4	200	2 9/16	2 7/16	61	7 11/16	3 11/16	40	10	4 15/16	30	7
13/16	184	7 3/4	2 15/32	60	10 5/16	3 23/32	40	5 7/8	4 31/32	30	4 3/4
7/8	171	5 1/2	2 1/2	60	1 1/4	3 3/4	40	1 7/8	5	30	2 1/2
15/16	160	1/2	2 17/32	59	4 3/8	3 25/32	39	9 15/16	5 1/32	30	1/4
1	150	1/2	2 9/16	58	7 3/4	3 13/16	39	6 1/16	5 1/16	29	10 1/16
1 1/16	141	2 11/16	2 19/32	57	11 1/4	3 27/32	39	2 3/16	5 3/32	29	7 15/16
1 1/8	133	4 3/4	2 5/8	57	3	3 7/8	38	10 7/16	5 1/8	29	5 13/16
1 3/16	126	4 3/8	2 21/32	56	7	3 29/32	38	6 3/4	5 5/32	29	3 11/16
1 1/4	120	5/8	2 11/16	55	11 1/8	3 15/16	38	3 1/8	5 3/16	29	1 7/16
1 5/16	114	4 1/8	2 23/32	55	3 7/16	3 31/32	37	11 1/2	5 7/32	28	11 1/2
1 3/8	109	1 3/4	2 3/4	54	7 15/16	4	37	8	5 1/4	28	9 1/2
1 7/16	104	4 15/16	2 25/32	54	9/16	4 1/32	37	4 1/2	5 9/32	28	7 1/2
1 1/2	100	3/4	2 13/16	53	5 7/16	4 1/16	37	1 1/8	5 5/16	28	5 1/2
1 9/16	96	3/4	2 27/32	52	10 3/8	4 3/32	36	9 3/4	5 11/32	28	3 1/2
1 5/8	92	4 1/2	2 7/8	52	3 1/2	4 1/8	36	6 3/16	5 3/8	28	1 9/16
1 25/32	90	7 1/16	2 29/32	51	8 13/16	4 5/32	36	3 1/16	5 13/32	27	11 5/8
1 11/16	88	11 1/2	2 15/16	51	2 1/4	4 3/16	35	11 15/16	5 7/16	27	9 3/4
1 23/32	87	4 1/8	2 31/32	50	7 13/16	4 7/32	35	8 3/4	5 15/32	27	7 7/8
1 3/4	85	9 7/16	3	50	1 1/2	4 1/4	35	5 11/16	5 1/2	27	6
1 25/32	84	3 7/16	3 1/32	49	7 5/16	4 9/32	35	2 9/16	5 17/32	27	4 3/16
1 13/16	82	10	3 1/16	49	1 1/4	4 5/16	34	11 9/16	5 9/16	27	2 3/8
1 27/32	81	5 1/4	3 3/32	48	7 3/8	4 11/32	34	8 9/16	5 19/32	27	9/16
1 7/18	80	5/16	3 1/8	48	1 9/16	4 3/8	34	5 5/8	5 5/8	26	10 13/16
1 29/32	78	9 1/4	3 3/32	47	7 7/8	4 13/32	34	2 11/16	5 21/32	26	9 1/16
1 15/16	77	6	3 3/16	47	2 5/16	4 7/16	33	11 7/8	5 11/16	26	7 5/16
1 31/32	76	3 1/4	3 7/32	46	8 13/16	4 15/32	33	9 1/16	5 23/32	26	5 9/16
2	75	1	3 1/4	46	3 1/2	4 1/2	33	6 1/4	5 3/4	26	3 15/16
2 1/32	73	11 3/16	3 9/32	45	10 3/16	4 17/32	33	3 1/2	5 25/32	26	2 1/4
2 1/16	72	9 3/4	3 5/16	45	5 1/16	4 9/16	33	13/16	5 13/16	26	9/16
2 3/32	71	8 3/4	3 11/32	45	1/16	4 19/32	32	10 1/8	5 27/32	25	10 15/16
2 1/8	70	8 1/8	3 3/8	44	7	4 5/8	32	7 1/2	5 7/8	25	9 5/16
2 5/32	69	7 7/8	3 13/32	44	2 1/8	4 21/32	32	4 7/8	5 29/32	25	7 11/16
2 3/16	68	7 15/16	3 7/16	43	9 3/8	4 11/16	32	2 3/8	5 15/16	25	6 1/2
2 7/32	67	8 3/8	3 15/32	43	4 11/16	4 23/32	31	11 13/16	5 31/32	25	4 9/16
2 1/4	66	9 1/8	3 1/2	43	1/16	4 3/4	31	9 5/16			
2 9/32	65	10 3/16	3 17/32	42	7 1/2	4 25/32	31	6 7/8			

In order to determine the radius of any simple curve of track, a straight edge 10 ft. long is laid against the rail on the inside of the curve or gage line, and the distance between the middle of the straight edge and curve on gage line, perpendicular to the straight edge is measured. This will give what is called the "middle ordinate." From this length the radius of the curve can be determined by reference to the table of middle ordinates on page 131. For example, if the distance was $2\frac{9}{32}$ ins., then the radius of the curve is 65 ft. $10\frac{3}{16}$ ins.

Rail bending to any radius is determined in the same manner.

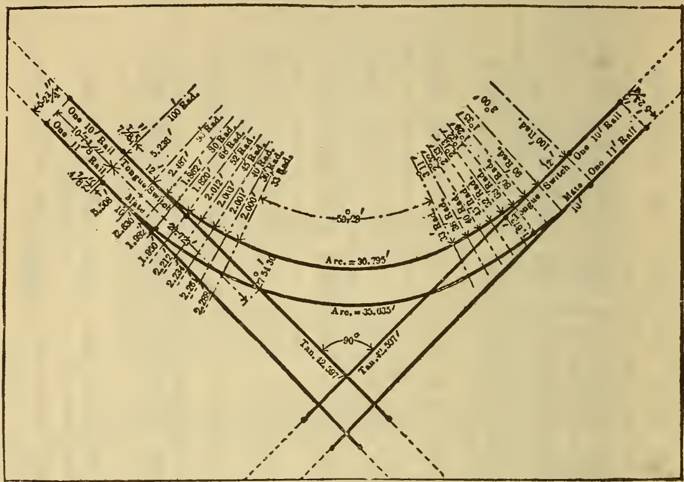


FIG. 137.—EASEMENT—STANDARD BRANCH-OFF SWITCH AT BOTH ENDS OF CURVE.

Super Elevation of Rails.—Where cars run rapidly around curves it is the practice where possible to elevate the outer rail in order to reduce the pres-

SUPER ELEVATION OF OUTER RAIL.

Radius of Curve in Feet.	3 Ft. Gage. Speed of Train in Miles per Hour.					3 Ft. 6 In. Gage. Speed of Train in Miles per Hour.					4 Ft. 8½ In. Gage. Speed of Train in Miles per Hour.				
	10.	20.	30.	40.	50.	10.	20.	30.	40.	50.	10.	20.	30.	40.	50.
40	4										$6\frac{1}{4}$				
50	$3\frac{3}{16}$					$3\frac{3}{4}$					5				
60	$2\frac{11}{16}$					$3\frac{1}{8}$					$4\frac{3}{16}$				
90	$1\frac{3}{4}$					$2\frac{1}{16}$					$2\frac{13}{16}$				
120	$1\frac{5}{16}$					$1\frac{9}{16}$					$2\frac{1}{8}$				
150	$1\frac{1}{16}$					$1\frac{1}{4}$					$1\frac{11}{16}$				
200	$\frac{13}{16}$	$3\frac{3}{16}$				$\frac{15}{16}$	$2\frac{3}{4}$				$1\frac{1}{4}$	5			
300	$\frac{9}{16}$	$2\frac{1}{8}$				$\frac{5}{8}$	$2\frac{1}{2}$				$\frac{13}{16}$	$3\frac{3}{4}$			
400	$\frac{3}{8}$	$1\frac{5}{8}$	$3\frac{9}{16}$			$\frac{1}{2}$	$1\frac{7}{8}$	$4\frac{3}{16}$			$\frac{5}{8}$	$2\frac{1}{2}$	$5\frac{5}{8}$		
600	$\frac{1}{4}$	$1\frac{1}{16}$	$2\frac{3}{8}$			$\frac{5}{16}$	$1\frac{1}{4}$	$2\frac{13}{16}$			$\frac{7}{16}$	$1\frac{11}{16}$	$3\frac{3}{4}$	$6\frac{11}{16}$	
800	$\frac{3}{16}$	$\frac{1}{16}$	$1\frac{13}{16}$	$3\frac{3}{16}$		$\frac{1}{4}$	$\frac{15}{16}$	$2\frac{1}{8}$	$3\frac{3}{4}$		$\frac{5}{16}$	$1\frac{1}{4}$	$2\frac{13}{16}$	5	

sure against rail and wheel flanges due to the centrifugal force exerted by the moving car. The table on preceding page gives the elevation allowed for different gages and speeds. Sometimes only one-half the elevation is given to outer rail and the the inner rail is depressed by the same amount.

For Bonding and Rail Connections see "Line Work," Section 5.

TRESTLE WORK.

Where trestles show less cost than filling, especially over marshy or soft ground, and over railway tracks, they may be built either of wood or iron. The combination of wooden approach trestle and iron lattice or girder spans over

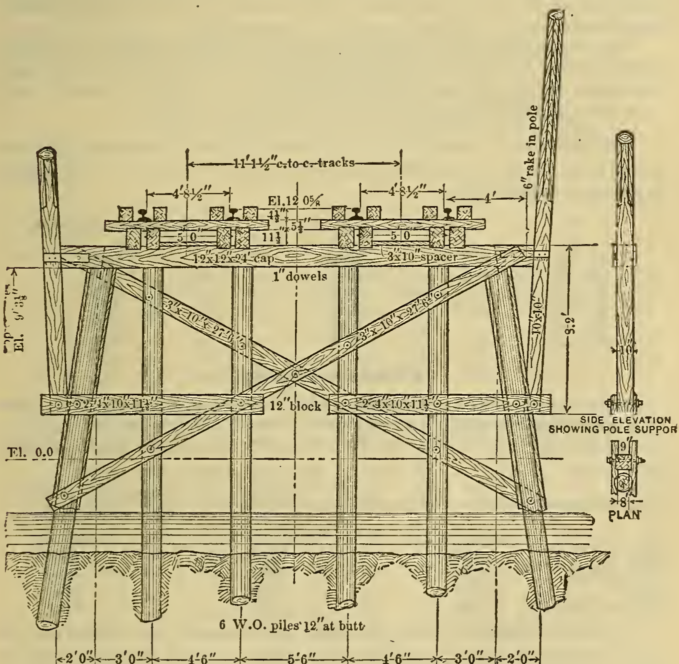


FIG. 138.

tracks where locomotives pass underneath is often used on account of danger from fire from sparks.

Fig. 138 gives an excellent form of trestle for marshes. (Designed by Ford, Bacon & Davis.) The following is the general data: The bents shown in Fig. 138 are 15 ft. apart for cars not weighing, loaded, over 25,000 lbs. at a speed not exceeding 16 miles per hour. There are six piles in each bent located as shown, in this case from 30 ft. to 45 ft. long, 10 ins. to 12 ins. top. The framing is long leaf yellow pine. The caps are 12 ins. x 12 ins. There are four girders underneath each track, 8 ins. x 12 ins.; the cross and longitudinal braces are 3 ins. x 10 ins.; the braces are thoroughly bolted, and the caps are secured by a 1-in. dowell pin from 18 ins. to 24 ins. in length driven in a $\frac{15}{16}$-in. hole, the dowell being covered with white lead before driving. The ties are 6 ins. x 8 ins. x 9 ft. yellow pine, spaced 18 ins. on centers; the guard stringers, one on each side of rail, are also yellow pine; the track centers are 11 ft. 1½ ins. apart, allowing two 9 ft. 6 in. car bodies to pass.

The mean given for the ultimate resistance to compression for white oak used as a post is 3470 lbs. per sq. in., and 4544 lbs. per sq. in. for yellow pine. 500 lbs. per sq. in. is the figure generally used, giving the proper factor of safety, for yellow pine.

The length of the post which will not yield, as found from tests made at the Watertown Arsenal is given in the table below. These tests were made upon rectangular yellow pine posts with flat ends having a length of from 5 ft. to 28 ft., and ranging in sectional area from 27 to 140 square inches.

The results may be generalized as follows, calling $\frac{l}{s}$ the ratio of length of post to least side of cross-section, and f the ultimate resistance to compression, in pounds per square inch:

$\frac{l}{s}$	f	RATIO OF DECREASE.
0 : 15	4000	1.00
15 : 30	3500	0.88
30 : 40	3000	0.75
40 : 45	2500	0.63
45 : 50	2000	0.50
50 : 60	1500	0.38

WOODEN BEAMS.

The following is a general summary of the results obtained by Prof. Lanza from numerous experiments upon wooden beams. They were of an average section of about 12 ins. x 4 ins. and were tested for mean span lengths of about 18 ft.

Kind of timber. Modulus of rupture $= \frac{M}{R} = \frac{\text{(Moment of forces causing rupture.)}}{\text{(Moment of resistance of cross section.)}}$

	MAXIMUM.	MINIMUM.	MEAN.
Spruce	5878	2995	4884
White Pine	6415	3438	4808
Oak	7659	4984	6075
Yellow Pine	11360	5092	7292

The above statement of the maximum and minimum values does not consider the results obtained in a few isolated cases for which the conditions were radically different than for the others. It was found that the beams frequently gave way through longitudinal shearing near the neutral axis, though this was not as common a source of failure as breaking across the grain.

For spruce the mean intensity of the shearing strains, for beams that failed in this manner, was 191 lbs. and for yellow pine 248 lbs. For beams that failed otherwise, the mean intensity of shearing strains at the moment of rupture was very nearly the same.

The conclusion appears, therefore, to be warranted that for soft timber there is an almost equal tendency for beams to fail by shearing longitudinally at the neutral axis, as by the tearing of the outside fibers.

Owing to the wide range of the results obtained and the generally erratic behavior of timber subjected to strains, Prof. Lanza recommends the following values for moduli of rupture to be adopted in practice.

Spruce and White Pine..........................3000 lbs.
Oak...4000 "
Yellow Pine.....................................5000 "

These values are lower than heretofore in use, and a safety factor of 4, on the basis of these values may be assumed as ample for all cases.

The following table has been calculated for extreme fiber strains of 750 lbs. per square inch:

SAFE LOADS, UNIFORMLY DISTRIBUTED, FOR RECTANGULAR SPRUCE OR WHITE PINE BEAMS.

One Inch Thick,
(For oak, increase values in table by one-third).
(For yellow pine, increase values in table by two-thirds).

Span in Feet.	Depth of Beam.										
	6″	7″	8″	9″	10″	11″	12″	13″	14″	15″	16″
5	600	820	1070	1350	1670	2020	2400	2820	3270	3750	4270
6	500	680	890	1120	1390	1680	2000	2350	2730	3120	3560
7	430	580	760	960	1190	1440	1710	2010	2330	2680	3050
8	380	510	670	840	1040	1260	1500	1760	2040	2340	2670
9	330	460	590	750	930	1120	1330	1560	1810	2080	2370
10	300	410	530	670	830	1010	1200	1410	1630	1880	2130
11	270	370	490	610	760	920	1090	1280	1490	1710	1940
12	250	340	440	560	690	840	1000	1180	1360	1560	1780
13	230	310	410	520	640	780	930	1080	1260	1440	1640
14	210	290	380	480	590	720	860	1010	1170	1340	1530
15	200	270	360	450	560	670	800	940	1090	1250	1420
16	190	260	330	420	520	630	750	880	1020	1180	1330
17	180	240	310	400	490	590	710	830	960	1100	1260
18	170	230	290	370	460	560	670	780	910	1040	1190
19	160	210	280	360	440	530	630	740	860	990	1130
20	150	200	270	340	420	510	600	710	820	940	1070
21	140	190	260	320	390	480	570	670	780	890	1020
22	140	190	240	310	380	460	540	640	740	850	970
23	130	180	230	290	360	440	520	610	710	810	920
24	130	170	220	280	350	415	500	590	680	780	899
25	120	160	210	270	330	410	480	560	660	750	860
26	110	160	210	260	320	390	460	540	630	720	820
27	110	150	200	250	310	370	440	520	610	690	790
28	110	140	190	240	300	360	430	500	580	670	760
29	110	140	180	230	290	350	410	490	560	640	740

To obtain the safe load for any thickness: Multiply values for one inch by the thickness of beam.

To obtain the required thickness for any load: Divide by safe load for 1 in.

For use in trestle work the load of car is treated as a live load, the bearing centers of load being the distance between wheel centers; using beams under this condition the beam will only take one-half on high speed roads, and two-thirds on moderate speed roads, of the loads given.

CAR HOUSE TRACK.

This is built generally on a slight grade toward the main track in order to facilitate the movement of the cars in case of fire. Several methods are used to

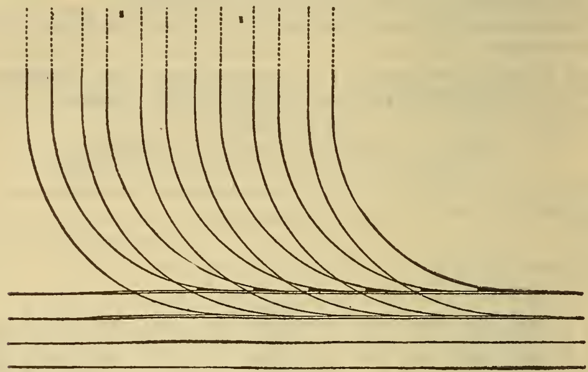


FIG. 139.

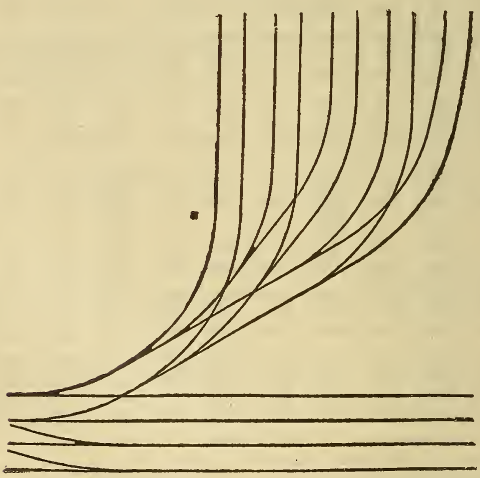


FIG. 140.

avoid breaking the main line rail when it is used for regular traffic especially where the switches have to face the direction of traffic. One is, where space is available, to run a track parallel to the main line track and to have all the car house tracks' switches on this auxiliary track.

Another method, a compromise from the parallel track, is to run a gauntlet track, Fig. 139, 6 ins. or 8 ins. from the main line track, and have the crossings all jump over frogs so that the main line track is unbroken to traffic. This requires two switches.

What is known as the ladder method (which is used extensively where the car house sets back from the track) shown in Fig. 140, is to run a spur from the main line track at an angle to the car house, and from this spur take the

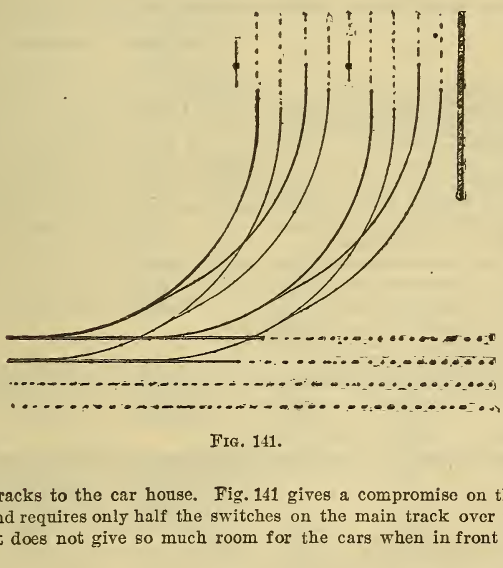


FIG. 141.

entrance tracks to the car house. Fig. 141 gives a compromise on the ladder method, and requires only half the switches on the main track over the direct curves, but does not give so much room for the cars when in front of the car house.

COST OF TRACK AND PAVEMENT.

The following estimates were made by John A. Beeler of the Denver City Tramway Company in 1893.

Section A. (Fig. 142)—This shows a 70-lb. T-rail (Shanghai) doing away with chairs, having a tie rod every four feet, which would make a very durable and serviceable track construction. This road is ordinary stone block pavement with one inch sand cushion and six inches of concrete for a base, as per city specifications, with a gravel foundation for track.

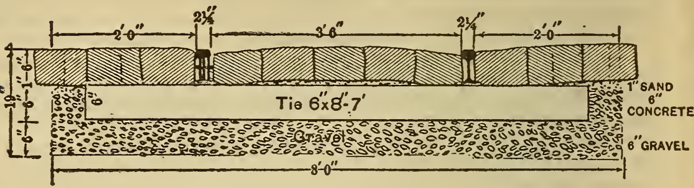


FIG. 142.—SECTION A.

Block Stone Paving on Concrete and Gravel. Ties 21" C. to C.

	Cost per Mile Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
110 tons rails (including freight, inspection and hauling) at $37.50 per ton	$ 4,125.00	46.667 lbs.	$0.7813
18,000 lbs. angle bars (360 per 50 lbs. each) at $2.01 per 100 lbs	361.80	3.409 "	0.0686
1,700 lbs. track bolts (⅞ x 3½ ins.) at $3.01 per 100 lbs	51.17	.322 "	0.0997
6,050 lbs. railroad spikes (5 x 9/16 ins.) at $2,46 per 100 lbs.	148.83	1.146 "	0.0282
1¼ M nut locks at $6.50 per M	8.12	....	0.0015
3,017 hewn red spruce ties at 55 cts. each	1,659.35	....	0.3143
360 bonds (placed complete) at 25 cts. each.	90.00	....	0.0171
1,320 tie rods at 20 cts. each	264.00	....	0.0498
2,347 cu. yds. excavation (trench 8 ft. wide 18 ins, deep, all hauled off) at 30 cts. per cu. yd	704.10	....	0.1334
Track laying, including blocking, etc	1,000.00	....	0.1893
	$ 8,412.37	....	$1.5932

Stone Paving 7.5 Feet Wide (Including 1 in. Sand Under Blocks.)

	Cost per Mile Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
4,400 sq. yds. (stone $1.50, laying 75 cts., sand, tar, etc. 50 cts.) at $2.75 per yd	$12,100.00	0.833 yd.	$2.2917
14,085 cu. ft. concrete (10 per cent cement 6 ins. deep between ties) at 15 cts. per cu. ft	2,112.75	2.669 C. ft.	0.4001
800 cu. yds. gravel under ties at 50 cts. per cu. yd	400.00	0.151 C. yd.	0.0758
22,000 ft. B. M. lumber (2 ins. x 14 ins. pine, retaining concrete, etc.) at $14. per M. ft	308.00	4.167 ft.	0.0583
Carpenter work, nails, hauling, etc	60.00	....	0.0113
Total cost per mile of paving	$14,980.75	....	$2.8372
Cost of paving per sq. yd. $3.40.			
Total cost per mile single track	$23,393.12	....	$4.4300

Section B. (Fig. 143)—Same track construction as Section A, and same paving, but a good foundation for track is provided by a continuous bed of concrete six inches deep under ties. This would make the most serviceable and durable construction for streets where stone blocks are to be used and, he thinks, would give best satisfaction. The additional cost of a foundation is very little when compared to the total cost.

Block Stone Paving on Concrete Foundation. Ties 21 ins. C to C.

	Cost per Mile Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
110 tons rails (including freight, inspection and hauling) at $37.50 per ton..........	$ 4,125.00	46.667 lbs.	$0.7813
18,000 lbs. angle bars (360 per 50 lbs. each) at $2.01 per 100 lbs....................	361.80	3.409 "	0.0686
1,700 lbs. track bolts (7/8 ins. x 3 1/2 ins.) including freight and hauling at $3.01 per 100 lbs............................	51.17	.322 "	0.0097
6,050 lbs. railroad spikes (5 ins. x 9/16 ins.) including freight and hauling at $2.46 per 100 lbs............................	148.83	1.146 "	0.0282
1 1/4 M nut locks at $6.50 per M.............	8.12	....	0.0015
3,017 hewn ties (6 ins. x 8 ins. x 7 ft.) red spruce, including hauling and inspection, at 55 cts. each....................	1,659.35	....	0.3143
360 bonds (placed complete) at 25 cts. each	90.00	....	0.0171
1,320 tie rods at 20 cts. each...............	264.00	....	0.0498
2,357 cu. yds. excavation (trench 8 ft. x 18 ins. deep all hauled away) at 30 cts per cu. yd..................................	704.10	....	0.1334
Track laying including blocking, etc......	1,000.00	....	0.1893
	$8,412.37		$1.5932

Stone Paving 7.5 ft. Wide (Including 1 in. Sand Under Stone Blocks.

	Cost per Mile Single track.	Quantities per Lineal ft.	Cost per Lineal ft.
4,400 sq. yds. (stone $1.50, laying 75 cts., sand, tar, etc. 50 cts.) at $2.75 per yd...	$12,100.00	0.883	$2.2917
11,734 cu. ft. concrete (10 per cent cement 5 ins. deep between ties) at 15 cts. per cu. ft......................................	1,760.10	2.222	0.3334
21,120 cu. ft. concrete (10 per cent cement 8 ft. wide 6 ins deep under ties) at 15 cts. per cu. ft..............................	3,168.00	4.000	0.6000
22,000 ft. B. M. lumber (2 ins. x 12 ins. pine for retaining concrete and pavement, at $14 per M..........................	308.00	4.167	0.0583
Carpenter work, nails, etc.................	60.00	.....	0.0113
Cost of paving per sq. yd. at $3.95.........	$17,396.10	.....	$3.2947
Total cost per mile single track........	$25,808.47	.....	$4.8879

Section C. (Fig. 144)—This track construction is good, heavy, 60-lb. steel with joint boxes. This rail is especially adopted for the Blake asphalt. In this section, track rests on a concrete foundation, with concrete to the top of the ties,

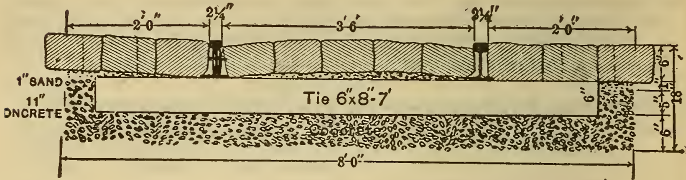


FIG. 143.—SECTION B.

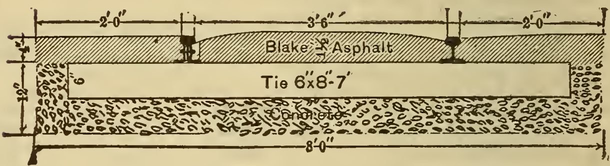


FIG. 144.—SECTION C.

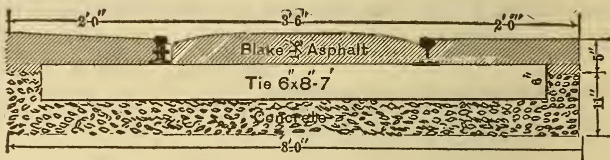


FIG. 145.—SECTION D.

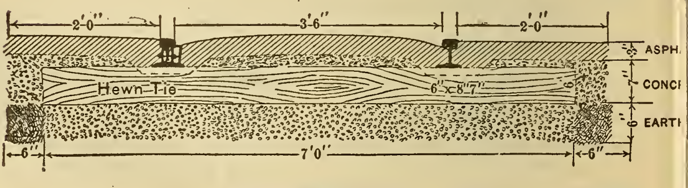


FIG. 146.—SECTION G.

with the Blake Asphalt paving. This section is not perfect, however. He states that the earth and dust are pounded in the crevice between the rail and asphalt by the wheel flanges, and works its way between the asphalt and concrete at the line at the top of the ties, bulging the paving, letting in the moisture and eventually destroying the asphalt.

Blake Asphalt Pavement. Ties 21 ins. C to C.

	Cost per. Mile Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
$94\frac{3}{10}$ tons steel rails (including freight, inspection and hauling) at $37.50 per ton..	$ 3,536.25	40.000 lbs.	$0.6697
10,800 lbs. angle bars (360 per 30 lbs. each, including hauling, etc.) at $2.01 per 100 lbs........	217.08	2.070 "	0.0411
1,150 lbs. track bolts (¾ ins. x 3½ ins., including freight and hauling) at $3.01 per 100 lbs........	34.62	.218 "	0.0066
6,050 R. R. spikes (5 ins. x $\frac{9}{16}$ ins. including freight and hauling) at $2.46 per 100 lbs.	148.83	1.146 "	0.0282
1¼ M nut locks at $6.50 per M..........	8.12	....	0.0015
3,017 hewn red spruce ties (including hauling and inspection) at 55 cts. each	1,659.35	....	0.3143
360 bonds (placed complete) at 25 cts. each.	90.00	....	0.0171
360 cast iron joint boxes at 50 cts. each....	180.00	....	0.0341
2080 cu. yds. excavation (trench 8 ft. wide 16 ins. deep, all hauled away) at 30 cts. each........	624.00	....	0.1181
Track laying, including blocking, etc......	1,000.00	....	0.1893
	$7,498.25	....	$1.4200

Asphalt Paving 7.5 ins. Wide, 4 ins. Thick.

	Cost per per Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
4400 sq. yds. at $2.60	$11,440.00	0.833	$2.17
14,085 cu. ft. concrete (10 per cent cement, 6 ins. deep between ties) at 15 cts......	2,112.75	2.669	0.40
21,120 cu. ft. concrete (10 per cent cement, 6 ins. below ties 8 ft. wide) at 15 cts....	3,168.00	4.000	0.60
25,700 ft. B.M. lumber (2 ins. x 14 ins. pine) retaining asphalt, etc., at $14..........	359.80	4.867	0.07
Carpenter work, nails, hauling, etc........	75.00	....	0.01
Cost of paving per sq. yd. $3.90............	$17,155.55	....	$3.25
Total cost track laying and paving....	$24,653.80	....	$4.67

Section D. (Fig. 145)—This section shows the same track construction with foundation, etc., but the asphalt is 5 ins. thick (1 in. deeper than in Section C). By this means the asphalt is bedded all around the rail, completely encasing it; hence the dirt cannot work in and deposit between the asphalt and concrete. This construction, however, is expensive, as too much asphalt is used.

Blake Asphalt Pavement, 1 in. Below Top of Tie. Ties 21 ins. C to C.

TRACK.	Cost per Mile Single Track	Quantities per Lineal ft.	Cost per Lineal ft.
Same as Section C	$ 7,498.25	....	$1.420
PAVING. (7.5 ft. wide, 5 ins. thick.)			
4400 sq. yds. Blake asphalt at $2.90	12,760,00	0.833 sq. yd.	2.417
11,734 cu. ft. concrete (10 per cent cement, 5 ins. deep between ties) at 15 cts	1,760.10	....	0.333
21,120 cu. ft. concrete (10 per cent. cement, 6 ins. deep below ties) at 15 cts.	3,168.00	6.222 cu. ft.	0.600
26,700 ft. B.M. lumber (2 ins. x 14 ins. pine) retaining asphalt and concrete at $14	359.80	4.867 ft.	0.070
Carpenter work, hauling, etc	75.00	....	0.010
Cost of paving per sq. yd., $4.12	$18,122.90	....	$3.430
Total cost of track and paving	$25,621.15	....	$4.850

Section G. (Fig. 146)—We will take this section up next, as it bears upon the two immediately above. Track construction same as above, but economizes upon the asphalt.

Here we have a concrete foundation, 6 ins. deep. under ties, and carry up the concrete above the ties, except for a space averaging 10 ins. wide directly under the rails, thus cementing the whole structure together, and giving a weariug surface of asphalt paving 3 ins. deep. (Barber asphalt is only 2½ ins.) The rails and ties where exposed, should be coated with tar or liquid asphalt just previous to laying the pavement, thus making it air and water tight.

This would be the ideal construction, and its cost will certainly be in its favor from the start.

Blake Asphalt Pavement. Cement Concrete Foundation. Ties 21 ins. C to C.

TRACK.	Cost per Mile Single Track.	Quantities per Lineal ft.	Cost per Lineal ft.
Same as Section C	$ 7,498.25	....	$1.420
PAVING.			
4400 sq. yds. Blake asphalt (7.5 ft. wide 3 ins. thick) at $2.25	9,900.00	....	1.875
36,178 cu. ft. cement concrete (see below) at 15 cts	5,426.70	....	1.027
25,700 ft. B.M. lumber (2 ins. x 14 ins.pine) at $14	359.80	....	0.068
Carpenter work, nails, hauling, etc	75.00	....	0.010
Cost per sq. yd., $3.58	$15,761.50	....	$2.980
Total cost track and paving	$23,259.75	....	$4.400

CONCRETE.	Cu. Ft.	Cu. Ft.	Cu. Ft.
Below ties (5280 ft. x 7 ft. x 0.5 ft.)	......	......	18,480
Between ties and 6 ins. from ends (5,280 ft. x 8 ft. x 0.5 ft.)	......	21,120	......
Less cu. ft. in ties (3017 ft. x 2.33⅓ ft.)	7,040	......	......
Less cu. ft. in space below rail	817	7,857	13,263
Above ties (5280 ft. x 6 ft. x 0.14 ft.)	......	......	4,435
			36,178

Section E.—This is a 60-lb. steel rail on chair construction with the necessary tie rods. Chairs are a little heavier than used formerly and if there is any error in these figures the principal one would be the price of the chairs, which would be very apt to cost more.

A 6-in. foundation of concrete below ties is calculated, and the space between the ties filled in with concrete; above this the Barber asphalt and stone toothing. With this foundation this is the same practical construction as used on portions of Stout and Arapahoe Streets, increased to a 60 lb. rail construction to compare with other proposed sections.

This is very expensive, and the chairs are an unmitigated nuisance. They should be avoided hereafter.

Barber Asphalt Paving. Stone Toothing, T Rail on Chairs. Hewn Ties 21 ins. C to C.

TRACK.	Quantities	Price	Cost per Mile Single Track	Cost per Lineal ft.
60-lb. T rail (including freight inspection and hauling...........	110 tons	$37.50	$ 3,536.25	....
Angle bars (360 per 50 lbs.) including freight, inspection and hauling.	13,000 lbs.	2.01	217.08	....
Track bolts (⅞ in. x 3½ ins.) including freight, inspection and hauling.......................	1,700 "	3.01	34.62	....
R. R. spikes (4 ins. x $\frac{7}{16}$ ins.) 750 to the keg, 200 lbs. each, 37¼ kegs	6,450 "	2.56	165.12	....
Nut locks.........................	1¼ M	6.50	8.12	....
Hewn ties (6 ins. x 8 ins. x 7 ft.) including inspection and hauling.	3,017	.55	1,659.35	....
Bonds in place....................	360	.25	90.00	....
Tie rods..........................	1,320	.20	264.00	....
Wrought iron chairs (4 ins. high)..	6,034	.60	3,620.40	....
Excavations (5280 ft. x 8 ft. wide x 20½ ins. deep.................	2,672 cu. yds.	.30	801.60	....
Track laying (including blocking).		....	1,250.00	....
	....	....	$11,646.54	....
PAVING.				
Concrete (7 ft. wide, 6 ins. deep) under ties, 10 per cent cement..	18,480 cu. ft.	.15	2,772.00	....
Concrete (8 ft. wide 6 ins. deep) between ties, 10 per cent cement.	14,085 "	.15	2,112.75	....
Barber asphalt paving, stone toothing (8½ ins. deep)..............	4,400 sq. yds.	3.15	13,860.00	....
Cost of paving per sq. yd., $4.26...	....	....	$18,744.75	....
Total cost of track and paving.	....	....	$30,391.29	$5.75

Section F.—This section has the same style of chair and track construction as in Section E with a stone block pavement instead of Barber asphalt; and includes the foundation under ties. The first figures are an estimate of cost based on figures for concrete and paving, and the second are based on the price paid for the paving on Wazee Street by the Board of Works.

Block Stone Paving, Concrete Foundation. T Rail on Chairs.

	Quantities.	Price.	Cost per Mile Single Track.	Cost Lin. ft.
TRACK.				
Same as Sec. E, less excavation......	......	......	$10.844.94	....
Excavation (trench 5,280 ft. x 8 ft. wide x 19 ins. deep).............	2,477 cu. yds.	.30	743.10	....
			$11,588.04	
PAVING.				
Stone block paving, 7.5 ft. wide, including 1 in. sand under blocks..	4,400 sq. yds.	2.75	12,100.00	....
Concrete 8 ft. wide, 6 ins. deep between ties, 10 per cent cement...	14,085 cu. yds.	.15	2,112.75	....
Concrete 7 ft. wide, 6 ins. deep under ties, 10 per cent cement..........	18,480 cu. ft.	.15	2,772.00	....
Lumber for retaining concrete and paving.........................	22,000 ft. B. M.	14.00	308.00	....
Carpenter work, nails, etc...........	......	......	60.00	....
Cost per sq. yd..................$3.94	......	......	$17,352.75	....
Total cost per mile, track and paving	......	......	$28,940.79	$5.48

Section Fa.—Block Stone Paving, Concrete Foundation.

	Quantities.	Price.	Cost per Mile Single Track.	Cost Lin. ft.
TRACK.				
Same as Section F....................	......	......	$11,588.04	....
PAVING.				
Stone block paving 7.5 ft. wide (including 1 in. sand and 6 ins. concrete under blocks................	4,400 sq. yds.	$3.50	15,400.00	....
Concrete under ties (7 ft. wide, 6 ins. deep) 10 per cent cement.........	18,480 cu. ft.	.15	2,772.00	....
Cost per sq. yard................$4.13	......	......	$18,172.00	....
Total cost per mile track, and paving	......	......	$29,760.04	$5.63

Summary.

	Foundation.	Sec.	Cost per Mile Single Track.	Cost Lin. ft.	Cost per Sq. yd.
Block stone paving, 70 lb. Shanghai rail............................	Concrete & Gravel	A	$23,393.12	$4.43	$3.40
Block stone paving, 70-lb. Shanghai rail............................	Concrete	B	25,808.47	4.89	3.95
Blake asphalt paving, 60-lb. T rail..	"	C	24,653.80	4.67	3.90
Blake asphalt paving, 60-lb. T rail..	"	D	25.621.15	4.85	4.12
Blake asphalt paving, 60-lb. T rail..	"	G	23,259.75	4.40	3.58
Barber asphalt paving, 60-lb. T rail on chairs......................	"	E	30,391.29	5.75	4.26
Block stone paving, 60-lb. T rail on chairs.........................	"	F	28,940.79	5.48	3.95
Block stone paving, 60-lb. T. rail on chairs (contract price)...........	"	Fa	29,760.04	5.63	4.13

For cross country roads the pavement should be left out of the estimate. The price of material will depend upon freightage and local costs. If the ties are spaced at a greater distance than 21 ins. between centers, the number of ties per mile for the different spacing is given in Table, Page 110.

The cost of laying a road parallel to country roads varies from 35 cents to 45 cents per running foot. Excavation costs from 23 cents to 45 cents per cubic yard depending upon local conditions. The price of bonds varies from 35 cents

FIG. 147.

FIG. 148.

to 65 cents per joint depending upon the current density in the rail. Bonds can be inserted and applied at an additional price of 14 cents to 30 cents per joint.

The effect of laying asphalt paving against the rail is shown in Fig. 147. Fig. 148 shows the methods used in New York in connection with cable tracks.

FIG. 149.

FIG. 150.

Fig. 149 shows method of paving with asphalt against the rails. Fig. 150 shows method of paving with asphalt with granite toothing block against the rails.

Paving Cost.—The following figures are from Washington, 1892: Trinidad asphalt with 7-in. concrete base, $2.25 per sq. yd.; Trinidad asphalt with 4 ins. concrete base, $2.00 per sq. yd.; Asphalt block, $2.00; asphalt surface, $17.00 cubic yard

Bituminous base, $3.00 per cu. yd. in place. Hydraulic cement and concrete, $5.00 per cu. yard in place. Asphalt surface, $1.02 per sq.yd. Annual average for repairs 3 cents per sq. yd.; resurfacing, $1.50 per sq. yd.

SECTION IV.—POWER STATION.

Power Station Location.—The factors affecting the proper location for the power station are the cost of land, the cost of copper for distribution, the cost of coal and the value of condensing water. The price that can be given for a piece of property in a central location is determined by the way in which this location affects the other investments and station economics.

Take, for example, a 15 mile stretch of road with cars uniformly placed requiring 20 amps. per mile average and 40 amps. per mile maximum, and assume 20 per cent drop in voltage on 7½ miles of road. With the station centrally located the copper will cost about $20,000; if the station is 2 miles from the center of distribution the installation cost for copper will be increased $6700. Property in the central location would, therefore, be worth this much more to the railway company as better distribution could be obtained from a station on that site.

Where the coal can be delivered directly from the cars to the coal bins of the station the cost for handling is the lowest. Where there is any rehandling, the price depends upon the distance traversed. To load and move 1 ton 1 mile or less costs about 25 cents per ton; 1½ miles, 30 cents; 2 miles, 32 cents. These figures are taken from average prices paid for hauling over a variety of roads. A station with the capacity mentioned above would require, on an average, about 11 tons of coal per day; if hauled 1 mile this would cost per year with shrinkage in coal weight due to moving, about $1000, or 6 per cent on an investment of $16,666.

The value of condensing in a street railway plant of the size cited above can be roughly estimated at 18 per cent saving in coal. At $2.80 per ton this would be $2023 per year or 6 per cent on an investment of $33,700. This station would take about 700,000 cu. ft. of water per annum for boiler use. If the water had to be bought, at say, $1 per 1000 cu. ft., a site would be worth $11,600 more where free water could be obtained.

Too often stations have been located on property owned by the railway which it would have been a great deal more economical to have given away, and located the station with reference to the least operating cost. The saving thus effected would, in many cases, pay interest on the investment on both properties. The location of the power station near the car house reduces in many ways the labor item, and the insurance hazard will not be increased if care be taken in the design. Another point to be considered is the liability for damages due to smoke nuisance, pollution of streams and external fire hazards.

FOUNDATIONS.

In locating the power station building the character of the soil and subsoil and its effect upon the cost of proper foundations for building and machinery should also be carefully determined. Every endeavor should be made to discover the character of soil on which the station foundations will rest. Where there are adjacent buildings these can be inspected and data as to the character, depth and weight per square foot of surface, obtained from the builders. Four borings should be made on the different sides of the site by using a post auger. If four borings show at the same depth the same character of soil, it can be assumed that there is no great dip to the strata. For those foundations which carry large weights, such as those under the chimney, the ground should be bored to a depth of 20 to 25 ft. This can be done by two men using a lever with a 6-in. or 8-in. auger. In soft soils a pipe must first be driven; a 4-in. pipe is a convenient size and a smaller auger can be used to bore the core out of the pipe. Different soils have greatly different bearing power and their safe loads are changed when the soils are wet. The table following gives the bearing power of soils as given by Ira O. Baker.

Bearing Power of Soils in Tons per Square Foot.

	MINIMUM.	MAXIMUM.
Rock, hard	25	30
Rock, soft	5	10
Clay on thick beds always dry	4	6
Clay on thick beds moderately dry	2	4
Clay, soft	1	2
Gravel and coarse sand well cemented	8	10
Sand compact and well cemented	4	6
Sand, clean and dry	2	4
Quick sand, alluvial soils, etc	0.5	1

There are many peculiarities of soils which should be thoroughly understood before applying the above table, as there is no more important point of the station building than its foundations.

The following remarks of a general character will serve as a guide to the street railway engineer in preliminary estimates.

Rock, when extending entirely under the building site, makes the best foundation bed. The softer rocks will sustain more weight than the walls resting on them can safely carry. Water is usually met with in substrata rock foundations, due to the seeping over them of the surface drainage; outside drains should be thrown around such a site. If the ledge of rock slopes to one side, a tile or stone drain may be built from the lowest to the highest point of the foundation footings and the water drained from the rock in this way. When nearly level, a hole should be blasted at the lowest point of the foundations and measures taken to dispose of the drainage water. The surface of the rock on which the foundations rest should be prepared, and all loose and decayed portions of rock in line of the foundation footings should be cut and dressed to a surface. If the rock surface is uneven, the surface should be cut in steps or plane surfaces: in no case should a wall rest on a sloping surface. All fissures or depressions should be carefully cleaned out to the hard rock surface and filled with cement to the level of the adjacent step. If deep cavities or fissures appear too large to fill, they may be bridged by arches of brick, stone or cement. In rock it is important that the different footings around the foundation of the buildings be as nearly on a level as possible. Where the building is to rest partly on rock and partly on soil the footings on the soil should be made very wide so the pressure per square foot will not be enough to cause an unequal settling of the foundations. These conditions of unequal sustaining power of the foundation bed should be avoided if possible as it is risky at best.

Clay. This designation covers soil conditions varying from slate and shale to soft, damp material, which will squeeze out in every direction when pressure is brought to bear upon it. Clay soils which can be kept dry and compact carry the usual loads without trouble, but clay as a rule gives more trouble than sand, gravel or stone.

The top footing in this case must be carried below the frost line, which varies from 6 ft. in Northern States to 2 ft. below the Mason & Dixon line. Freezing affects clay more than other soils, so that the drainage of foundations on this character of soil must be taken care of, and when on a slope the foundations are considered hazardous. If the clay contains coarse gravel or stone its retaining power is greatly increased.

Gravel gives less trouble than any other material for foundation bed if the foundations are properly proportioned, and it is not affected by water provided the gravel and sand cannot wash away from under the foundation footings.

Sand, if confined from lateral movement, makes an excellent foundation. If no water can move it, it is practically incompressible. Dry, clean river sand so confined has been known to carry 100 tons to the square foot. All foundation footings in sand should be carried to the same level, and when the engine and boiler foundations are separate from the building structure, the building footings should be carried below the bed of any internal foundation, thus making the building wall the retaining wall for the internal foundation stress on the sand.

Soils Containing Vegetable Matter. No foundation should be laid on soils containing vegetable matter or land that has been filled. The original virgin bed of the soil should be reached unless the filling is made of clean beach sand, that has been made compact by drenching with water as it was filled; and this should be treated and retained as required for foundations on sand.

Mud or Silt can only be used by extending the foundation area on the surface by spreading the footings on wooden or steel beams, by sinking beams or pillars until hard soil is reached, or by driving piles distributed over the foundation bed so as to take the weight of the structure uniformly.

Some Data on Soils.—The Capitol at Albany rests on blue clay containing 60 per cent to 90 per cent alumina, the remainder being fine sand containing 40 per cent water. The safe load was taken at 2 tons per square foot; a load of 5.9 tons per square foot produced an upheaval of surrounding earth.

The Congressional Library at Washington, D. C., rests on yellow clay mixed with sand; 13½ tons were required to produce settlement and the footing was proportioned for 2½ tons per square foot.

Hard indurated clay under the piers of the bridge across the Ohio River at Point Pleasant, West Virginia, carries 2½ tons per square foot.

The Cincinnati Bridge foundation bed is of coarse gravel 12 ft. below water and carries 4 tons per square foot.

The Brooklyn Bridge foundations are 44 ft. below bed of river and rest on bed rock and a layer of sand, 2 ft. thick. This material resists a maximum pressure of 5½ tons per square foot.

Methods of Testing Foundations.—One method suggested is to construct a platform about 4 ft. square with 4 legs each 6 ins. square, the platform being set on the bottom of the foundation trench and carefully leveled. A level should be set up so that the levels on each leg of the bench are taken, a level is also taken to a bench mark on a stake or some fixed point. A uniform load is then gradually placed over the platform until a settling is noticed. From one-fifth to one-half of the load that produced the settling of the platform can be allowed on the foundations, the proper factor of safety being governed by circumstance.

When the footings for foundations are soft or treacherous, piles are largely used in station construction. The following data is taken from Kidder's "Building Constrnction and Superintendence."

Piles should always be driven with small ends down, with all bark and branches trimmed close. The pile driver should strike the pile squarely on its head. The usual weight of hammers are from 1200 to 1500 lbs., the hammer falling from 5 to 20 ft., the last blows being given with quick strokes in succession and not over 5 ft. fall. Do not continue to drive piles when they sink only 1½ ins. under five blows of a 1200 lb. hammer falling 15 ft.

Bearing Value of Piles.

Character of Soil.	Pile Length in Feet.	Average Diameter.	Penetration.	Load in Tons.
Silt	40	10	6	2¼
Mud	30	8	2	6
Soft earth with boulder or logs	30	8	1½	7
Moderately firm earth or clay with boulder or logs	30	8	1	9
Soft earth or clay	30	10	1	9
Quicksand	30	8	½	12
Firm earth	30	8	½	12
Firm earth into sand or gravel	20	8	¼	14
Firm earth to rock	20	8	0	20
Sand	20	8	0	20
Gravel	15	8	0	20

When the penetration is less than that given above for soft soils the safe load may be increased.

Foundation Courses.—The foundation may be either stone, brick or concrete as local prices and character of foundation dictates. A lower course of

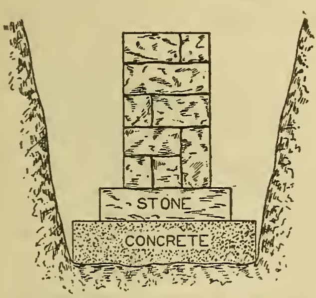


Fig. 151.—CONCRETE FOOTING.

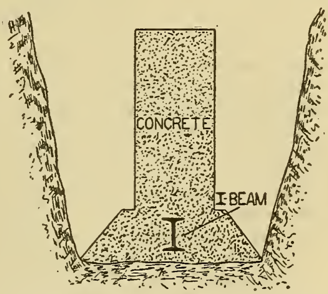


Fig. 152.—CONCRETE FOUNDATION.

concrete having a spreading base, like Fig. 151 gives a good bearing for any superstructure, as the concrete, when well tamped, conforms to the contour of the earth, and as large stone should be used for the footing courses, concrete makes the cheaper foundation.

Concrete foundations as a whole are largely used in power station construction, and where the supporting power of the soil varies, I-beams or rails are imbedded in the concrete to bridge the inequalities of bearing surface, Fig. 152.

The piles should in no case be driven closer than 2 ft. on centers. The usual spacing is 2 ft. 6 ins. across the foundation trench, and 3 ft. along the line of wall.

The capping of piles may be of cement. see Fig. 153, well tamped with concrete. The earth should be excavated 1 ft. below the top of piles and 1 ft. outside of them, the space around and between them being filled with a rich Portland cement deposited in layers. Piles should always be surfaced below the water mark, where water stands on the foundation, to prevent decay, and in no case should piles be used in dry soil.

Materials for Foundations.—The materials used in foundation construction are lime, cement, sand, broken stone, brick and building stones; these materials are specified as to quality and the proportions which will be used in making mortar, cements and concretes.

Lime.—Common lime, sometimes called quick lime or caustic lime, is produced from limestones by heating to redness or calcination. These vary in composition in different parts of the country. Good lime should show the following characteristics: Entire freedom from cinders and clinkers, and the other impurities should not exceed 10 per cent; it should be in hard lumps with little dust; it

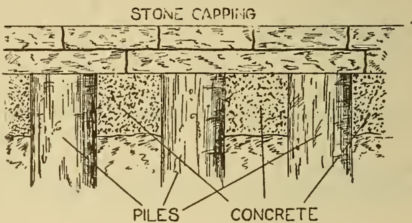


FIG. 153.—PILE FOUNDATION.

should slack freely in water forming a fairly smooth paste with very little or no residue; it should dissolve in rain water. Hydraulic lime should harden under water after it has been made in a cake and has commenced to stiffen in air.

Natural Cements.—Natural cements are made from natural rock composed of carbonate of lime, carbonate of magnesia and clay. Care is required in selecting the stone, calcining to the proper degree and inspecting after calcination; it is then finely ground between mill stones. The natural cements are very quick in setting, but have less ultimate strength than the artificial, or Portland; they attain their full strength sooner, and are sufficiently strong for ordinary building operations; they cost less than Portland and are used almost exclusively for cement mortar. They weigh less than Portland, being about two-thirds as heavy. The locations where natural cements are made on a large scale are Rosendale, N. Y., Louisville, Ky., Utica, N. Y., La Salle, Ill., Milwaukee, Wis., Maukato, Minn., Cement, Ga. and Fort Scott, Kan.

In Rosendale cement a light color usually indicates an inferior, underburnt rock. Rosendale varies in weight from 49 to 56 lbs. per cubic foot or 60 to 70 lbs. per bushel.

Artificial Cements.—The artificial cements are usually known as Portland, and require a homogenous mixture in the proper proportions of carbonate of lime, alumina, silica and iron; this mixture is subjected to heat sufficient to produce a vitrified, dense and hard clinker and is afterward ground to powder. The American Portland cements have been used in the largest engineering works in this country. Good Portland cement is slow setting in comparison with the natural cements, and in setting forms a crystalline structure similar to the natural zeolites. Portland costs approximately three times as much as Rosendale, but its strength makes its use in stone or brick foundation footings necessary, as it carries loads of over 1½ tons per foot, and should be preferred for these uses over any of the natural cements.

Mortars.—Mortars are made of lime slacked in a water-tight box; water is then added. Different limes take different volumes of water. The water is rapidly absorbed, and with a rise in temperature the ultimate volume of slacked lime is about 3½ times the original lime; sand is then mixed with this, the proportions being about one part of lime to five of sand. Rich mortar contains a larger proportion of lime than above. Mortar of good quality slides readily from the trowel; if it sticks there is too much sand in its composition. The usual practice is to mix the sand with the lime as soon as it is slacked, and let it stand until ready for use. Better results are obtained if the sand is not mixed with the slacked lime until the mortar is needed.

Sand.—Sharp sand should show angular formation of granules of various sizes. If there is any doubt as to the cleanness, the sand can be tested by putting some in a tumbler of water. If there are any impurities present they will rise to the top. On squeezing moist sand in the hand the sand should fall loosely down; if it retains the impression of the hand it should be rejected, as it contains loam which greatly weakens the binding power of the mortar.

Cement Mortar.—This should be used for all work which is exposed to dampness or to the weather. The sand and cement are thoroughly mixed dry, and water added and mixed until the proper consistency is reached. This mortar works better when stiff. For natural cements it should not exceed 3 parts of sand to 1 of cement; for structures bearing heavy weights 2 to 1 should be used; Portland cement can be used in the proportion of 4 or 3 to 1, for first class mortars. For foundations under water a greater ratio than 2 to 1 should not be used. When a cheaper cement will answer, slacked lime is added instead of more sand.

Kidder gives the following estimates:

Lime Mortar: 1 barrel of lime weighs 270 lbs., a bushel of lime weighs 75 lbs., 1 barrel of lime equals 3 bushels; 1 cu. yd. of sand will make 1 yd. of 1 to 3 lime mortar and will lay about 80 cu. ft. of rough brick work or common rubble.

Cement Mortar: 1.8 barrels, 540 lbs. of natural cement, and .94 cu. yds. of sand will make 1 cu. yd. of 1 to 3 mortar; 2 lbs. of Portland cement and .94 cu. yds. will make 1 cu. yd. of 1 to 3 mortar; 1 cu. yd of mortar will lay from 67 to 80 cu. ft. of brick work or rough rubble, and from 90 to 108 cu. ft. of brick work with ⅜-in. to ¼-in. joints. A cubic foot of brick work contains about 18 bricks.

The following safe crushing strength of mortars per sq. ft. is usually divided by 8 for safe loads.

Portland cement mortar, 1 to 3	3 months, 40 tons	1 year, 65 tons
Rosendale " " " "	" " 13 "	" " 26 "
Lime mortar " "	" " 8.6 "	" " 15 "

Lime mortar should not be used under piers that are to receive their full load within six months.

Grout is a very thin mixture of cement mortar used to fill interstices in stone work, and usually poured on the courses of masonry, or run between stones to be bonded.

Concrete.—This consists of cement mortar to which is added crushed stone. Granite and other hard stones make the best aggregates. It is essential that the crushed stone should be free from dirt. The sizes vary from those that will pass through a 1-in. ring up to the size of a hen's egg. Clean gravel is also used largely in some sections. The usual way that the proportioning of parts is accomplished is by the wheelbarrow load where the mixing is done by hand, one barrel of cement being taken in two barrow loads. The materials are dumped on a water-tight platform; the sand is first spread and then the cement is laid over it; these two materials are thoroughly mixed and on this mixture is dumped the broken stone, which is mixed in dry; then water is added, still continuing the mixing, until all portions are thoroughly coated.

Many machines have been devised for mixing cement to save labor. The Pittsburgh power station was built largely of concrete using an automatic mixer. The proportion of the parts vary with the size of the broken stone used, and the crushing strain on the concrete structure. There should always be enough cement to fill all voids in the stone.

Concrete for foundations, bearing only a moderate weight, can be made of 1 part natural cement, 2 parts sand, and 4 parts gravel or broken stone. Portland concrete to take heavy weights should have 2 parts cement, 5 parts sand and 9 parts broken stone. Where a larger proportion of stone is used, the cement should be carefully tested as the building progresses, and close inspection is necessary to see that the proportions are carefully maintained.

The concrete is delivered to the foundation trenches, which may be cut out in clay, and the concrete rammed into position; when sand or yielding earth compose the trenches, wooden cribs have to be constructed against which the concrete is rammed to give the size and shape of the foundation required. The layers should not be more than 6 ins. thick, and the concrete should not be dropped from a greater height than 4 ft; each layer is to be rammed with a wooden, 20-lb. rammer until the top surface shows a flush of water and all interstices are completely filled.

General Remarks.—The strains that Portland cement can take are from 1 to 5 tons per square foot; natural cement concrete, 1 to 6 tons per square foot.

Where the proportions are 1 part cement, 3 parts sand, 5 broken stone, size not exceeding 2 × 1½ × 3 ins., one barrel of cement will make 22 to 24 cu. ft. of concrete.

Concrete : 1 part of cement, 2½ of sand, 3 of gravel and 5 of broken stone, yields 1.18 yds. of concrete per barrel of cement. With labor at $2.00 per day, mixing and depositing should not exceed $1.00 per cubic yard. The cost of Portland concrete will vary from $6.00 to $8.00 per cubic yard.

STATION WALLS.

These may be of brick, stone or concrete, iron and brick, terra cotta with iron beams, iron beams with concrete walls, wooden post and siding of novelty or shingle. The choice of material depends upon the cost and character of structure required. The walls of a station over the engine room and boiler room do not have to carry more than the roof weights unless the crane, steam piping or office floors are above. The prevalent form of brick station structure is to build brick piers or buttresses, the distances between centers being the same as between the centers of the roof trusses. Between the piers are thin curtain walls of brick, largely taken up by windows. These piers are bonded at the top by girders. The thickness of continuous brick walls are often fixed by ordinance; nearly all building regulations requiring approximately the following thickness: for buildings carrying heavy floor weights, two stories, brick 16 ins., stone 20 ins.; three stories, brick 20 ins., stone 24 ins.; four stories, brick 24 ins., stone 28 ins.

Station walls of cut stone may be constructed either with a plain face or buttresses, the space between buttresses as a rule being arched for window openings, and the surface stone work and facings being left to the taste of the architect. Brick, either red or terra cotta or glazed, or concrete can form the external walls. The structure is sometimes supported by the buttresses of masonry, and in some forms of construction contains within the brick walls, columns or pillars, which carry the roof load. This latter construction is used where space has to be economized, and where the roof weights to be carried would require larger foundation areas than could be well distributed by a masonry buttress.

The building may be an iron or steel skeleton with thin double walls of brick, terra cotta or even concrete. In some cases a single brick wall faced on the inside with the numerous forms of compositions for ceiling and interior work is used.

For temporary work corrugated galvanized iron or tin, or galvanized iron stamped with brick tiling, having an inside sheathing of wood or asbestos millboard has been found satisfactory. For further protection the space between the inner and outer walls, when wooden, can be filled with dry clean cinders or mineral wool.

In wooden structures the walls can be of novelty siding or dipped shingles laid over 1-in. spruce boarding. The inside wall can be of adamantine plastering laid on metallic or wooden lathes, the spaces between being filled with mineral wool or cinders to make a slow burning structure. Another form is to have all timber dressed; on the outside are nailed 2-in. hemlock planks dressed on the inside; over this the building paper and novelty siding or shingles are nailed. Eight feet can be carried between the posts. This character of construction reduces the insurance rates on wooden buildings, and makes what is known as the "slow burning" construction.

The weights that the buttresses, pillars or struts have to bear in a power station engine room are usually the roof weights, and the moving crane and load. The distance between the spans varies from 6 ft. to 20 ft. depending upon the character of the roof trussing employed. In the smaller stations it is much more economical to use horses or cranes tracked on the floor than to strengthen the roof truss for rigging machinery.

For strengths of building materials see tables on pages 11 to 15.

ROOFS.

Weights and strains thrown on the roof are due to wind pressure and snow. The wind pressure allowable depends upon exposure of building; 32 lbs. per square foot should not exceed the ultimate strength of the structure.

Pressure of Winds on Roof. (Unwin).

a = Angle of surface of roof with direction of wind.
F = Force of wind in pounds per square foot.
A = Pressure normal to surface of roof.
B = Pressure perpendicular to direction of wind.
C = Pressure parallel to direction of wind.

Angle of roof $= a$	5°	10°	20°	30°	40°	50°	60°	70°	80°	90°
$A = F \times$	.125	.24	.45	.66	.83	.95	1.00	1.02	1.01	1.00
$B = F \times$	.122	.24	.42	.57	.64	.61	.50	.35	.17	.00
$C = F \times$	.01	.04	.15	.33	.53	.73	.85	.96	.99	1.00

Angles of Roofs as Commonly Used.

Proportion of Rise to Span	Angle Deg.	Angle Min.	Length of Rafter to Rise.
½	45	....	1.4142
⅓	33	41	1.8028
$2\sqrt{3}$	30	....	2.0000
¼	26	34	2.2361
1-5	21	48	2.6926
1-6	18	26	3.1623

Velocity and Pressure of Winds. (Hurst.)

Designation.	Velocity in Miles per Hour. V.	Pressure in Lbs. per Sq. Ft. P.
Scarcely perceptible	1	.005
Perceptible	2	.020
Slight breeze	4	.080
Moderate breeze	8	.320
Fresh breeze	15	1.125
Brisk wind	25	3.125
Strong wind	30	4.50
High wind	40	8.00
Storm	50	12.50
Violent storm	60	18.00
Hurricane	80	32.00
Violent hurricane	100	50.00
Gust observed at Liverpool Observatory in 1868	126	80.00

The weights of the different kinds of roofing are as follows:

	Lbs. per Sq. Ft.
Cast iron plates	15
Copper	.8 to 1.25
Felt and asphalt	1
Felt and gravel	8 to 10
Iron, corrugated	1 to 3.75
Corrugated sheets, unboarded	8
Iron galvanized, flat	1 to 3.50
Sheathing, pine 1 in. thick, yellow	3 to 4
Shingles on lathes	10
Spruce, 1 in. thick	2
Spruce, if plastered below rafters	12
Sheathing, 1 in. chestnut or maple	4
Slate on lathes	13
Slate on boards 1¼ in. thick	16
Sheet iron $\frac{1}{16}$ in. thick	3
Sheet iron and lathes	5
Skylights, glass $\frac{3}{16}$ in. to ½ in	2.50 to 7
Sheet lead	5 to 8
Tin	.7 to 1.25
Tiles, flat	15 to 20
Tiles, grooved and fillets	7 to 10
Tiles, pan	10
Zinc	1 to 2

For spans over 75 ft. add 4 lbs. per square foot to the above loads.

Snow weighs 5 lbs. to 12 lbs. per cubic foot depending upon the humidity of the atmosphere; 1 cu. ft. of snow compacted by rain weighs 15 lbs. to 50 lbs. It is customary to add 30 lbs. per square foot to the above for snow and wind when separate calculations are not made.

The weight of any load upon a roof is taken as uniformly distributed over the surface of the roof. The total weight on each pair of rafters, couple or truss, is equal to the sum of the weights of the truss itself, and as much of the roof as is carried between two trusses.

Safe Loads, in Tons of 2,000 Lbs. for Hollow Cylindrical Cast Iron Columns.

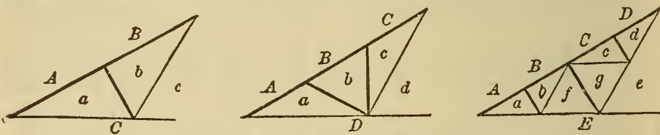
Outside diam. inches	Thickness of Metal	LENGTH OF COLUMNS IN FEET									Sectional Area, inches	Wght. lbs. of columns per ft. of length
		8	10	12	14	16	18	20	22	24		
		Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons		
6	½	26.2	23.0	20.1	17.5	15.2	13.2	11.5	....	....	8.6	26.95
6	¾	37.5	33.0	28.8	25.0	21.7	18.9	16.5	....	....	12.4	38.59
6	⅞	42.7	37.6	32.8	28.5	24.7	21.5	18.8	....	....	14.1	43.96
6	1	47.6	41.9	36.5	31.8	27.6	24.0	21.0	....	....	15.7	49.01
6	1⅛	52.2	46.0	40.1	34.8	30.2	26.3	23.0	....	....	17.2	53.76
7	¾	47.7	43.1	38.5	34.3	30.4	26.9	23.9	21.2	18.9	14.7	45.96
7	1	61.1	55.2	49.3	43.8	38.9	34.4	30.6	27.1	24.2	18.9	58.90
7	1⅛	67.2	60.8	54.3	48.3	42.8	37.9	33.7	29.9	26.7	20.8	64.77
8	¾	57.9	53.3	48.6	44.1	39.7	35.8	32.2	28.9	26.1	17.1	53.29
8	1	74.6	68.7	62.5	56.7	51.1	46.0	41.4	37.3	33.6	22.0	68.64
8	1¼	89.9	82.8	75.5	68.4	61.7	55.5	49.9	44.9	40.5	26.5	82.71
9	¾	68.1	63.6	58.9	54.2	49.6	45.2	41.2	37.5	34.1	19.4	60.65
9	1	88.0	82.3	76.2	70.0	64.1	58.4	53.2	48.4	44.1	25.1	78.40
9	1¼	106.6	99.6	92.2	84.8	77.6	70.8	64.4	58.7	53.4	30.4	94.94
9	1½	123.8	115.7	107.1	98.5	90.1	82.2	74.8	68.1	62.0	35.3	110.26
9	1¾	139.6	130.5	120.8	111.1	101.6	92.7	84.4	76.8	69.9	39.9	124.36
10	1	101.4	95.9	89.8	83.6	77.4	71.5	65.8	60 5	55.5	28.3	88.23
10	1¼	123.3	116.5	109.1	101.6	94.1	86 8	79.9	73.4	67.5	34.4	107.23
10	1½	143.7	135.8	127.3	118.5	109.7	101.2	93.2	85.6	78.7	40.1	124.99
10	1¾	162.7	153.8	144.1	134.1	124.2	114.6	105.5	97.0	89.1	45.4	141.65
11	1	114.8	109.4	103.5	97.3	91.0	84.8	80.2	73.1	67.7	31.4	98.03
11	1¼	139.9	133.3	126.2	118.6	110.9	103.3	97.8	89.4	82.5	38.3	119.46
11	1½	163.5	155.9	147.5	138.6	128.7	120.8	114.3	104.1	96.4	44.8	139.68
11	1¾	185.7	177.1	167.5	157.5	147.3	137.2	129.8	118.3	109.5	50.9	158.68
11	2	206.6	196.9	186.3	175.1	163.8	152.6	144.4	131.5	121.8	56.6	176.44
12	1	128.0	122.9	117.2	111.0	104.7	98.4	92.2	86.1	80.4	34.6	107.51
12	1¼	156.4	150.1	143.1	135.7	127.9	120.2	112.6	105.2	98.2	42.2	131.41
12	1½	183.3	175.9	167.7	159.0	149.9	140.9	132.0	123.3	115.1	49.5	154.10
12	1¾	208.7	200.4	191.0	181.1	170.7	160.4	150.3	140.5	131.1	56.4	175.53
12	2	232.7	223.4	213.0	201.9	190.4	178.9	167.6	156.6	146.1	62.8	195.75
13	1	141.2	136.3	130.7	124.7	118.5	112.1	105.8	99.5	93.5	37.7	117.53
13	1¼	172.8	166.8	160.0	152.7	145.0	137.2	129.4	121.8	114.4	46.1	143.86
13	1½	203.1	195.5	187.9	179.3	170.3	161.1	152.0	143.1	134.3	54.2	168.98
13	1¾	231.6	223.6	214.5	204.7	194.4	183.9	173.5	163.3	153.3	61.9	192.88
13	2	258.9	249.9	239.7	228.7	217.3	205.5	193.9	182.5	171.3	69.1	215.56
14	1	154.3	149.6	144.3	138.5	132.3	125.9	119.5	113.1	106.8	40.8	127.60
14	1¼	189.2	183.4	176.9	169.7	162.2	154.4	146.5	138.6	131.0	50.1	156.31
14	1½	222.6	215.8	208.1	199.7	190.8	181.7	172.3	163.1	154.1	58.9	183.67
14	1¾	254.4	246.7	237.9	228.3	218.1	207.6	197.0	186.5	176.2	67.4	210.00
14	2	284.8	276.2	266.4	255.6	244.2	232.4	220.6	208.8	197.2	75.4	235.12
15	1	167.4	162.9	157.8	152.1	146.0	139.7	133.3	126.8	120.4	44.0	137.28
15	1¼	205.5	200.0	193.7	186.7	179.3	171.5	163.6	155.7	147.9	54.0	168.48
15	1½	242.1	235.7	228.2	220.0	211.2	202.1	192.8	183.5	174.2	63.6	198.74
15	1¾	277.2	269.8	261.3	251.9	241.9	231.4	220.7	210.1	199.5	72.9	227.45
15	2	310.8	302.5	293.0	282.5	271.2	259.5	247.5	235.5	223.6	81.7	254.90

Columns for the support of roof trusses are generally of the box-girder type of steel. Cast-iron columns, where eccentric loading occurs, are not largely used, on account of the internal strains in castings and the variable thickness in walls. Cast-iron columns will carry the weights given in the table on page 155, where used to support a uniformly distributed load, e. g. pillars for supporting floors or internal structures in the station.

The top and bottom of every iron column should be trimmed off to a smooth surface, the length of the column is the distance between these surfaces.

Roof Trusses.—Tables for finding stresses in members for roof trusses of the different types and pitches as given below and of any span.

Rule.—To find the stress in any member multiply the coefficient given for that member by total dead load carried by truss (= span in feet × distance be-



FIGS. 154 TO 156.—ROOF TRUSS DIAGRAMS.

tween trusses in feet × weight per square foot). If the truss is acted upon by wind forces, or other unsymmetrical loading, the stresses in the members must be calculated accordingly and combined with the dead load stresses as found below.

	Pitch (Depth to Span.)			
Member of Truss	⅓	30°	¼	⅕
Fig. (154)				
Aa	.675	.750	.838	1.010
Bb	.537	.625	.726	.917
Ca	.563	.650	.750	.938
Cc	.375	.433	.500	.625
ab	.208	.217	.224	.232
bc	.188	.217	.250	.313
Fig. (155)				
Aa	.750	.833	.930	1.120
Bb	.589	.666	.757	.928
Cc	.568	.666	.783	.995
Da	.625	.721	.833	1.042
Dd	.375	.433	.500	.625
ab	.155	.167	.180	.202
bc	.155	.167	.180	.202
cd	.250	.288	.333	.417
Fig. (156)				
Aa	.788	.874	.978	1.178
Bb	.718	.812	.922	1.131
Cc	.649	.750	.866	1.085
Dd	.580	.687	.810	1.038
Ea	.655	.758	.875	1.094
Ef	.562	.650	.750	.938
Ee	.375	.433	.500	.625
ab	.104	.108	.112	.116
bf	.093	.108	.125	.156
fg	.208	.216	.224	.232
gc	.093	.108	.125	.156
cd	.104	.108	.112	.116
ge	.187	.217	.250	.313
de	.280	.325	.375	.469

NOTE.—Heavy lines denote compression and light lines tension members. Loads are considered as concentrated at the joints.

Figs. 157 show the lattice type of roof truss as designed by the Berlin Iron Bridge Co., and Fig. 158 shows the standard roof truss designed by the same company.

It is not within the province of this book to go into the mechanical details of such structures, for the considerations upon which the calculations for these

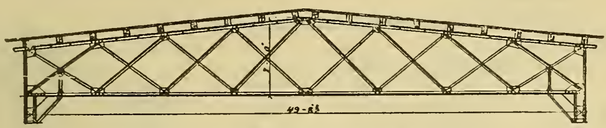


FIG. 157.—LATTICE TYPE OF ROOF TRUSS.

structures are based would occupy too much space, and have been fully developed in such books as Kidder's "Building Construction and Superintendence" for wooden roofs, Kent's "Mechanical Engineer's Pocket-Book" and a number of other technical works bearing on the different parts of the structural designs and such data has been selected as will give the railway engineer enough information to lay out what is required.

One requirement of a power station roof is that it shall be non-condensing. Metal roofs have to be lined with some non-conductor of heat; an enclosed air space should be left between the outside roofing and the lining so the warm air inside will not condense and drip on the machinery. With corrugated iron roofs and steel trusses, asbestos roofing board, supported by wire netting, has been used with success, especially where the space between the roof and inside paper has been closed so as not to admit of outside circulation. In some stations

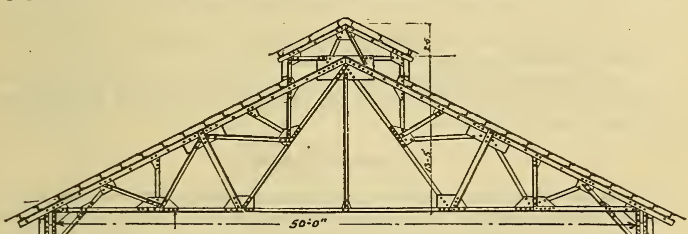


FIG. 158.—STANDARD ROOF TRUSS.

tar and gravel are used on roofs not exceeding 30 degrees pitch. The construction is as follows: To the purlins are nailed 3-in. tongued and grooved plank of yellow pine parallel to the trusses, and on this three layers of tar paper are nailed and again over this is spread tar or pitch and covered with clean gravel until the tar is covered. Over boiler rooms asphalt, which melts at a higher temperature, mixed with sand, is used. Papers, such as Paroid or Asbestos Roofing Felts, have been used over matched board roofs.

Fig. 159 shows a construction as applied to a roof of 64 ft. span. The trusses are connected by iron purlins of 10-in. channels, which carry three lines of rafters, consisting of 4-in. channels parallel to the top chords of the trusses. Upon the rafters are laid longitudinal lines of angle iron $\frac{1}{4} \times 1\frac{3}{8}$ ins., spaced $13\frac{3}{8}$ in. center to center. Directly upon these are laid Ludowici tiles, being of such form as to interlock with each other and form a watertight joint. Every fourth tile is secured to the angle irons by a piece of copper wire passed through the lug in the tile and wound around the angle iron. No cement is required in making a water-

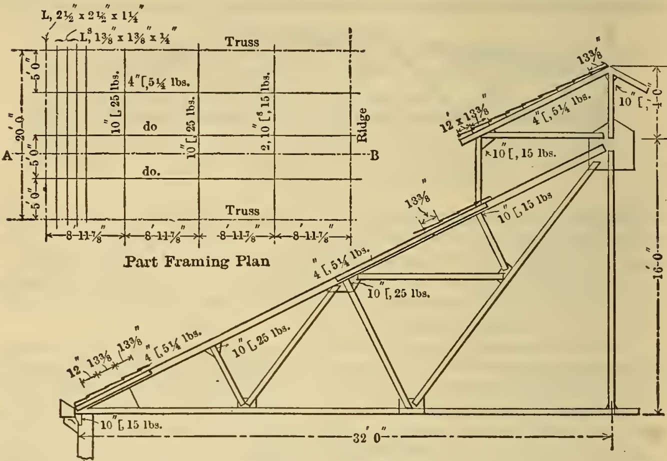


Fig. 159.—SECTION OF TRUSSED ROOF SPAN.

tight roof, but in exceptional cases the joints may be pointed on the under side to make them proof against dust and fine snow.

The tiles are of hard burned terra-cotta, 9 × 16 in. in size, or 135 pieces to the square. The weight is 750 to 800 lbs. per square. (In measuring roof surfaces 100 sq. ft. make a "square.")

STATION FLOORS.

I-beam girders with concrete or brick arches or some form of tile are largely used for station flooring. The conditions are such that in erecting or assembling machinery, heavy loads may be placed on these floors, and provision must be made that they bear these weights without yielding. The floors are generally figured at 150 to 300 lbs. per sq. ft. and the table below gives the proper spacing for I-beams.

For ordinary station floors the cross-line on the column of figures indicates where the deflection on the beam is greater than $\frac{1}{360}$ of the distance between supports, or $\frac{1}{30}$ in. per foot. With such flexure on beams carrying plastered ceilings, there is danger of the ceiling cracking. The weight of a floor is taken as that of the variable floor load and the load of the flooring structure.

Fig. 160 gives the common methods of connecting floor joists. Where a number of I-beams are used close together, for supporting floor loads, separators should be bolted between them to prevent side deflection and buckling. In floor construction in several stations, concrete girders have been formed having imbedded in them twisted rods as tie rods. The distance between the concrete girders which

Spacing of Carnegie I-Beams for Uniform Load of 150 Lbs. per Square Foot.

WEIGHTS GIVEN IN POUNDS PER FOOT.

PROPER DISTANCE IN FEET, CENTER TO CENTER OF BEAMS.

Distance between supports in feet.	20″ I.		15″ I.				12″ I.		10″ I.		9″ I.
	80 lbs.	64 lbs.	80 lbs.	60 lbs.	50 lbs.	41 lbs.	40 lbs.	32 lbs.	33 lbs.	25 lbs.	21 lbs.
12	71.5	56.6	51.8	42.4	34.9	27.9	23.1	18.3	15.9	12.1	9.3
13	61.0	48.2	44.1	36.2	29.7	23.8	19.7	15.6	13.6	10.3	7.9
14	52.5	41.6	38.0	31.2	25.6	20.5	17.0	13.5	11.7	8.9	6.8
15	45.8	36.2	33.1	27.2	22.3	17.9	14.8	11.7	10.2	7.7	5.9
16	40.3	31.8	29.1	23.9	19.6	15.7	13.0	10.3	8.9	6.8	5.2
17	35.7	28.2	25.8	21.1	17.4	13.9	11.5	9.1	7.9	6.0	4.6
18	31.8	25.1	23.0	18.9	15.5	12.4	10.3	8.1	7.1	5.4	4.1
19	28.5	22.6	20.6	16.9	14.0	11.1	9.3	7.3	6.3	4.8	3.7
20	25.7	20.4	18.6	15.3	12.5	10.0	8.3	6.6	5.7	4.4	3.3
21	23.3	18.5	16.9	13.8	11.4	9.1	7.5	6.0	5.2	3.9	3.0
22	21.3	16.9	15.4	12.6	10.4	8.3	6.9	5.5	4.7	3.6	2.7
23	19.5	15.4	14.0	11.6	9.5	7.6	6.3	5.0	4.3	3.3	2.5
24	17.9	14.1	12.9	10.6	8.7	7.0	5.8	4.6	4.0	3.0	2.3
25	16.5	13.1	11.9	9.8	8.1	6.4	5.3	4.2	3.7	2.8	2.1
26	15.3	12.1	11.0	9.0	7.4	5.9	4.9	3.9	3.4	2.6	2.0
27	14.1	11.2	10.2	8.4	6.9	5.5	4.6	3.6	3.1	2.4	1.8
28	13.1	10.4	9.5	7.8	6.4	5.1	4.3	3.3	2.9	2.2	1.7
29	12.3	9.7	8.9	7.3	6.0	4.8	3.9	3.1	2.7	2.1	1.6
30	11.5	9.1	8.3	6.8	5.6	4.5	3.7	2.9	2.5	1.9	1.5

Distance between supports in feet.	8″ I.	7″ I.	6″ I.	5″ I.	4″ I.	3″ I.
	18 lbs.	15 lbs.	13 lbs.	10 lbs.	7 lbs.	6 lbs.
5	41.1	30.9	22.3	14.1	8.1	4.9
6	28.5	21.4	15.5	9.8	5.6	3.4
7	20.9	15.8	11.3	7.2	4.1	2.5
8	16.1	12.1	8.7	5.5	3.2	1.9
9	12.7	9.5	6.9	4.3	2.5	1.5
10	10.3	7.7	5.6	3.5	2.0	1.2
11	8.5	6.4	4.6	2.9	1.7	1.0
12	7.1	5.4	3.9	2.4	1.4	0.9
13	6.1	4.6	3.3	2.1	1.2	..
14	5.2	3.9	2.8	1.8	1.0	..
15	4.6	3.4	2.5	1.6	0.9	..
16	4.0	3.0	2.2	1.4	..	..
17	3.5	2.7	1.9	1.2	..	..
18	3.2	2.4	1.7	1.1	..	..
19	2.9	2.1	1.5	1.0	..	..
20	2.6	1.9	1.4	..	..	..
21	2.3	1.7	1.3	..	..	..
22	2.1	1.6	1.1	..	..	..

For load of 300 lbs. per square foot, divide the spacing given by 2. Maximum fibre strain, 16,000 lbs. per square inch.

were 8 ins. wide × 16 ins. deep, in one case was 6 ft. The wooden forms are made for the girder in position and in them, in the proper position, are placed the tie rods; then rich concrete is rammed into place, the arch between girders

FIG. 160.—METHOD OF CONNECTING FLOOR JOISTS.

forming one continuous construction, and being made at the same time as the girders. This floor has stood a test up to 400 lbs. per square foot.

The objection to a concrete floor surface for a station is that the surface is

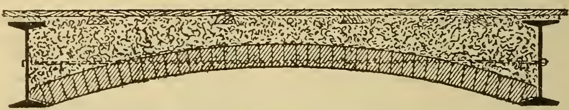


FIG. 161.—FIRE PROOF FLOOR: BRICK.

continually being worn off by the movment of the feet over it. This raises a dust in the station which enters the oiling system and bearings and leads to trouble with the machinery. In one water-power station washing down of the floors had

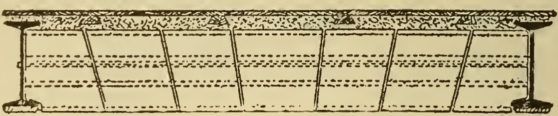


FIG. 162.—FIRE PROOF FLOOR: HOLLOW POTTERY.

to be resorted to as the bearings commenced to heat shortly after each sweeping of the floor.

To avoid this the floor can be treated with hot paraffin, which is burnt into it with a flame so that it will not be a superficial coating; this prevents the

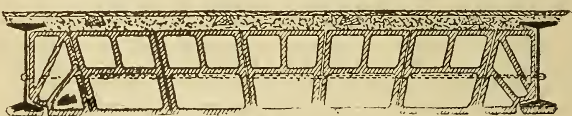


FIG. 163.—FIRE PROOF FLOOR: HOLLOW POTTERY.

erosion of the concrete surface. Oils have been tried but they make the floor slippery and increase the chance of a flash fire.

The old method of constructing fire-proof brick floors was to use a single 4-in. course of brick with a rise of 3 ins. to 4 ins. and resting on the lower flanges of the I-beams against brick skewbacks, Fig. 161. The weight of a fire-proof floor of this description, exclusive of beams averages about 70 lbs. per square foot.

For floors designed for heavy loads several courses of brick are used. Where wood floors are to be laid over concrete construction, wooden nailing strips should be imbedded in the concrete. There are special burnt clays known as hollow pottery or porous earthenware. The form of construction generally used is shown in Figs. 162 and 163. Tie rods should always be used with arches between I-beams as shown.

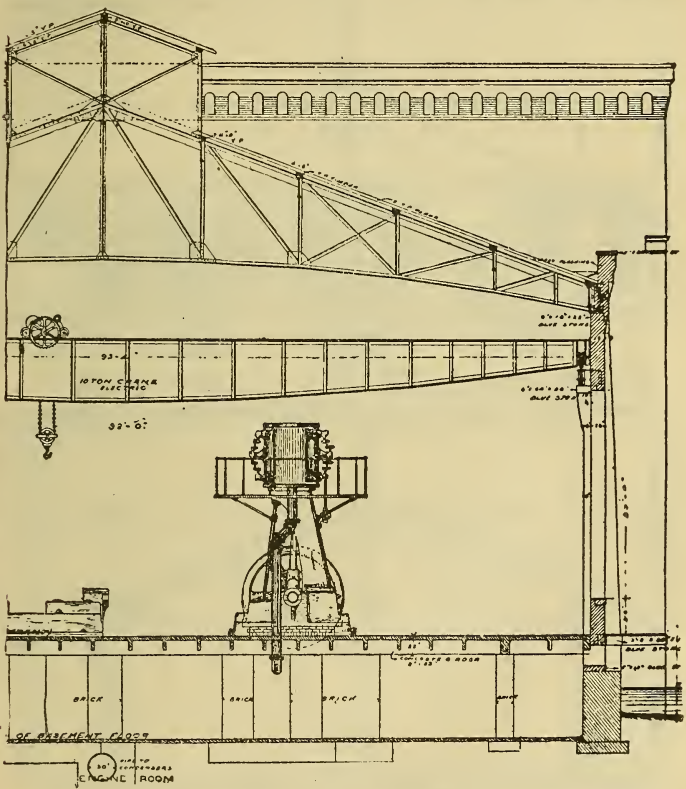


FIG. 164.—SECTIONAL VIEW OF PATERSON STATION.

Wooden floors should be of hard non-resinous wood, maple being one of the best. The wood should be thoroughly seasoned and laid tight to prevent the accumulation of oil, which constitutes a fire hazard. Diamond iron plates, tile and tessellated floors are used in some stations; with these floors oiling systems which keep all oil off the floors should be provided, otherwise they are very slippery.

In boiler rooms, concrete will not stand the heat where ashes are discharged on the floor, or constant shoveling is required in firing. Iron diamond plates make a better surface than brick or flagging laid in concrete.

TYPICAL CENTRAL STATIONS.

Fig. 164 gives the cross-section of a station at Paterson, N. J. The span of the roof truss is 92 ft., the walls are brick, the buttress slopes from the ground

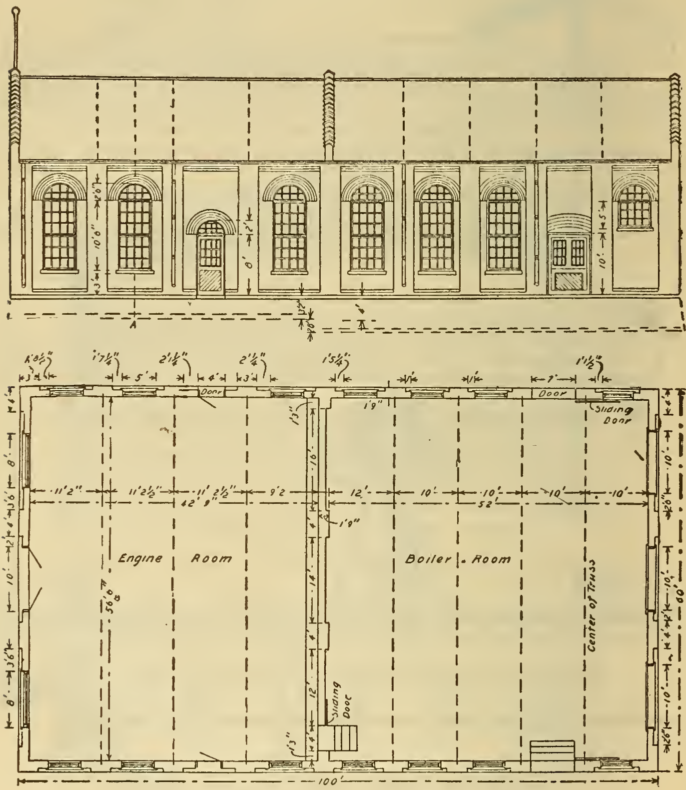


FIG. 165.—ST. LOUIS & BELLEVILLE STATION.

floor where it is 16 ins. wide and flush with the wall. Where the roof truss bears from the floor to bottom of roof, the truss at the wall is 23 ft. 6 ins. The thickness of the wall is 16 ins.; inside buttress, 8 ins.; the spans are 18 ft. 6 ins. apart;

the width of buttress 3 ft.; the walls on the side of the buttress, 2 ft. 8 ins.; window opening, 10 ft. 3 ins.

The 10-ton crane track is supported by a blue stone capping on buttress as shown. The foundation is of concrete and the trimmings of blue stone.

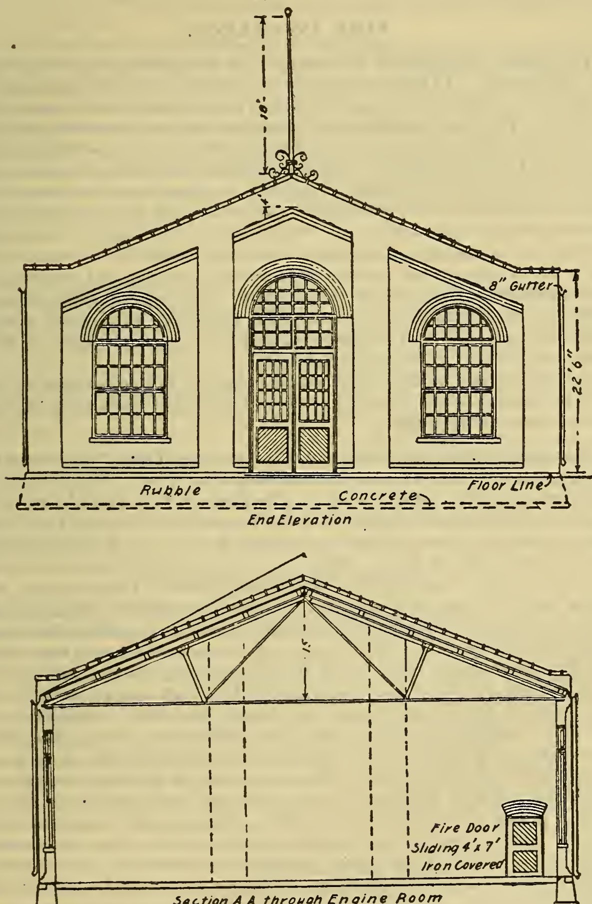


FIG. 166.—ST. LOUIS & BELLEVILLE STATION.

Figs. 165 and 166 show the construction of the St. Louis & Belleville Electric Railway station, containing two Corliss engines, 625 hp. each, direct-connected to two generators, 425 kw. each, and four boilers in two batteries with an output of 1000 hp. It will be noticed that the foundations under the station extend the whole area of the station. The structure is selected as being typical of modern construction for small stations.

FIRE INSURANCE.

The charges for insurance are based on the fire hazard presented by the stations construction. As this is a fixed charge against the plant per annum every precaution should be taken in construction to reduce the rate to the lowest possible figure. Fire-proof construction throughout brings the lowest rate. This applies to buildings in which all parts that carry weights or resist strain, and also all stairs and elevator enclosures and their contents are made of entirely incombustible material, and in which all metallic structural members are protected against the effects of fire by coverings of a material which must be entirely incombustible and a poor heat conductor. The materials which shall be considered as fulfilling the conditions of fire-proof covering are: first, brick; second, hollow tiles of burnt clay applied to the metal in a bed of mortar and constructed in such a manner that there shall be two air spaces of at least ¾ in. each adjacent to the metal surface to be covered; third, porous terra-cotta which shall be at least 2 ins. thick, and shall also be applied directly to the metal in a bed of mortar; fourth, two layers of plastering on metal lath.

Wooden stations, where erected within 18 ins. of the line between the lot on which they stand and the adjoining property, should have brick walls on the side next to the adjoining property.

Insurance Rules for Standard Electric Light and Power Stations. —Walls: brick or stone, at least 8 ins. in thickness, or iron. Height: one story, without story or space below. Area : not over 5000 sq. ft. of ground area between standard fire walls. Roof: metal, with metal trusses and supports. Floor: brick, cement, stone or earth. Wooden platforms may be used about machines. Cornice: brick stone or metal. Eaves: not less than 15 ft. from ground. Finish: no combustible finish or finish leaving concealed spaces. Division walls, if any, to be of brick, or stone with standard fire doors or shutters. Partitions about offices, storerooms or elsewhere to be of non-combustible material. Boiler, except in standard station, to be outside, or cut off by standard fire wall with standard fire doors and shutters. Wall to be 8 ins. for one-story station, and 4 ins. to be added for each additional story; wall to extend through and at least 3 ft. above roof. Roof of boiler house should have proper ventilator. Stack: brick, or if iron, to be outside and on brick foundation. Wire tower, if any, to be brick or stone with same kind of roof as station proper. Stairs, if any, to be properly enclosed when deemed necessary. Elevators, if any, to be in brick tower or with self-closing hatches. Heating to be by steam, hot water or hot air by blower system; piping for same to be free from woodwork and supported by iron hangers. Stoves may be used in office. Lighting to be by gas, brackets so arranged as not to allow flame to come in contact with woodwork; or by electricity, wiring to be in accordance with rules. Occupancy to be only for legitimate uses of the station itself. Exposure: unexposed to other hazards within 50 ft.; or if exposed to have approved fire walls on exposed sides.

Sprinklers are sometimes required in an engine room; these should be located so that in no case can the dynamo or switchboard be wet. It is very doubtful whether they are useful in the engine room; in the boiler room they might be valuable, although in many boiler rooms the temperature rises high enough at times to cause them to operate and be troublesome.

Where stations are erected adjacent to hazardous buildings, pipes have been run parallel and near to the eaves of the roof, drilled with holes and connected to the water supply so the side of the building near the hazard can be drenched with water in case of fire.

Wooden floors in a station always raise the insurance rate, and in most cases, fire-proof flooring will be a good investment; it is to be remembered that after a rate is placed on a station property it is very hard to reduce it, whereas with proper fire precautions embodied in the original design a low rate can be secured, or the station can afford to carry its own insurance, and following the usually wise precautions advised by the fire underwriters, can save a large sum per annum. The matter of fire pumps and tanks required vary in different localities, and the underwriters should be consulted to get their specific requirements in each case of contemplated construction.

GENERAL STATION ARRANGEMENTS.

There are general arrangements regarding levels of the different parts of the station which should be adhered to if possible, in order to get the best results from the necessary apparatus in the power station. Where the boilers deliver their steam to a header above them, in order to get dry steam it is advisable not to drop the steam pipe system below the header any more than possible. This brings the boiler foundation naturally below that of the engines. If the exhaust from the engines be taken to a condenser, the condenser should be low enough to take the condensed water by gravity. This brings the level of the heaters and condenser below the exhaust of the engine. Again in surface condensers or heaters where the hot water has to be fed to the boiler again by pumps, in order to deliver this hot water, the pump should be located below the source of water. It is thus evident that the levels of the internal station foundations should be carefully arranged to give the best results in both steam and water circulation.

INTERNAL FOUNDATIONS.

The foundations required by boilers, engines and generators may be built internally, independent of the foundation structure, or the whole building foundation can be extended from wall to wall, forming a monolith type of foundation. This type of station foundation is largely used where the character of the ground is not such as to warrant the required pressure per square foot to sustain the internal structures. Under each head below will be given the general methods used in foundation construction for boilers, engines and generators.

The location of the boilers is determined by the ease of handling coal and ash disposal and the ventilation of the boiler room, and they should be so arranged as to require the least lengths and surface of steam pipe from them to reach the engines. The foundations for each type of boiler, its dimensions and character are usually given by the manufacturer; the dimensions given in this Hand Book should be used only in laying out and locating. It is customary for the boiler manufacturer to supply with their bids, plans and settings for the boilers estimated on. The weights per square foot should be obtained for the boiler to be erected and foundation made amply large, so that the boiler weight will not cause a settling. The foundation for boilers usually is not given sufficient attention: cracks in boiler walls reduce the efficiency of the boiler and stack due to air leaks.

Where the ground is of such character as not to take the boiler load under the foundation footings as required, piling can be resorted to, or a concrete monolith can be made, extending the length and width of the room occupied by the boilers. Structural iron can be buried in this mass but should be located away from the heating effects of the fire. As concrete is seriously weakened by heat, the boiler wall should be raised at least 12 ins. above the concrete bed and constructed of brick; on this the boiler walls are built. Boiler settings are taken up in the case of the different boilers described. In this concrete bed can be formed the ash pits and air ducts necessary.

THE BOILER.

Determination of Capacity.—In railway plants the boiler has to have sufficient capacity to make up for all the losses in the steam and electric transmission and transforming systems. There are a number of factors that have to be considered in fixing the proper boiler capacity. If the contour of the road and the schedules are such as to bring intermittent overloads on the plant, as may arise when the city is located at a lower level than the surrounding country which the railway serves, a periodic overload will be brought upon the station depending upon the schedule followed by the cars. Another periodic overload may occur where the schedule is so fixed in a road that a number of equipments are climbing grades at the same moment. Under the section on "The Equipment" will be found the necessary power that has to be furnished for a given weight of equipment, speed, grade, etc. The line transmission losses will be determined by the length of feeders to supply the various sections and the conductivity of the ground return. Data for this determination will be found under "The Line." These losses have to be added to the power required for moving the cars under maximum load conditions.

The steam consumption of the engine will vary with the different types and loads which will be found under the heading of the "Steam Engine." The auxiliary appliances, such as pumps, condensers, blowers, steam heating appliances and steam pipe condensation also require steam from the boilers, and allowance must be made for them. The addition of all these factors, when based on the hp-hour, will give the mean steaming capacity of the boilers required.

In railway work, another condition which often arises, is where specially congested traffic occurs such as at ball grounds, parks and other places of amusement. This causes temporarily a large demand. In some cities the traffic on a Sunday or holiday doubles the number of equipments on the schedule. Then again the character of the business carried on in a certain district will impress itself upon the load curves of the station. In industrial towns extra traffic will be required to carry the workmen both at 7 a. m. and 6 p. m., and under normal conditions the traffic is heavier at these hours than any other period of the day. If the cars are heated electrically this is too important a factor to be neglected in the boiler installation, as it has amounted to 20 per cent on level roads of the total output. Snow plows and sweepers, and snow on the track also bring an additional demand on the boiler plant.

The number of cars operated changes largely the character of the steam demand on the boilers. (See Data for Engine Sizes.) The larger the road the more nearly the load diagram averages a straight line except at the two peaks at 7 a. m. and 6 p. m. On roads with moderate grades the demand is averaged when the equipments are not so located on the schedule that they are climbing the grades simultaneously. Heavy grades accentuate momentary demands.

The other points that reflect upon the capacity of the boilers required for a given service are the matters of draft, temperature of the feed water and steaming quality of the coal to be used. There are physical conditions to be met in the steam supply in railway work which are of importance. Among them are the sudden variation of load demand on the boiler and its capability of producing a large amount of dry steam. In the specifications for the steam delivery it is important to know the length of time and extent of this demand. This sudden demand will also tend to produce foaming in the boilers which will mechanically carry over water to the piping system.

Outside the boiler the steam can be dried by superheating coils placed in the furnace, steam separators in the steam main, and throttling at the engine, so that the steam in expanding will take up the superfluous moisture. But these are simply auxiliaries to take care of the steam in case of improper boiler actions.

It is inadvisable to force too small a boiler plant to meet these overloads as it will cost more in depreciation than the interest on the cost of a sufficient boiler capacity in the first installation. The units should be divided up for the required steam output in such a way that under the most adverse conditions, under the combination of the heaviest load, bad weather and poor coal and with one unit of the boiler plant being laid off for cleaning or repairs, the station can still operate without hazardous forcing of the boilers. It is hardly advisable even in the smallest plants to consider less than three boiler units, two of which are capable under normal conditions of maintaining the station load at full potential. It is often advisable in boiler specifications, instead of detailing the size of boiler units required, to specify what the boiler plant must deliver in pounds of dry steam per hour with a moisture not exceeding 1 per cent for the maximum overload that will fall on the station, and allowing the boiler manufacturer to divide this steam delivery into the most economical boiler units that he can supply. Some of the different types of boilers have certain capacities in which their proportions are most favorable, whereas by increasing or diminishing the size of that type the results are not as satisfactory.

The fire-tube type of boiler is limited in its dimensions and output by the tensile strength of iron employed. Where boiler space is limited a larger output can be obtained from the water-tube boilers, and the maximum output for a given floor space can be obtained from the vertical type of boiler.

Having fixed the number of pounds of steam required at the given pressure, by referring to the Table of Properties of Steam (pages 19 and 20), which gives the factors of evaporation, there can be found the number of pounds to be evaporated from and at 212 degs. Fahr. By multiplying this figure by 965.7, the number of heat units per hour to be delivered by the boiler will be found. Dividing the equivalent pounds evaporated per hour by 34½ gives the boiler horse-power.

The common heat unit is the British Thermal Unit, known as B. T. U., and is that quantity of heat which is required to raise the temperature of one pound of cold water one degree Fahrenheit. The boiler horse-power is the evaporation of 34½ lbs. of water from and at 212 degs. Fahr., or its equivalent; this is equal to the conversion in the boiler of 33,317 B. T. U. per hour. This is often used for the rating of the capacity of a boiler, and has been defined by the boiler test committee of the American Society of Mechanical Engineers, Code of 1898, as follows: "A boiler rated at any stated capacity should develop that capacity when using the best coal ordinarily sold in the market where the boiler is located, when fired by an ordinary fireman, without forcing the fires, while exhibiting good economy; and further, the boiler should develop at least one-third more than the stated capacity when using the same fuel and operated by the same fireman, the full draft being employed, and the fires being crowded; the available draft at the boiler, unless otherwise understood, being not less than ½ in. water column."

General Boiler Proportions.—It is essential in any boiler that sufficient provision be made to burn the required amount of coal. This includes the area of the grate surface, the proportions of the stack and the size of flues. The determination of these details involves the quality of coal, kind of furnace, rate of combustion and skill of the fireman.

The pounds of coal which will be required per hour can be obtained by dividing the equivalent of evaporation from and at 212 degs. Fahr. per hour, in pounds, by the weight of water that may be evaporated from and at 212 degs. by 1 lb. of coal. The very best grade of Western bituminous coal, low in ash, in a proper furnace has evaporated 12 lbs. of water per lb. of coal, the boiler being proportioned and designed to absorb 75 per cent of all the heat generated in the furnace. This has fallen as low as 5 lbs., or less, of water per pound of coal with a poor grade of Western bituminous coal and poor furnace conditions for complete combustion. In a boiler having insufficient heating surface, the author has obtained as low results as 4.1 lbs of water per pound of coal, 20 per cent ash, burned under boilers with grates unsuited to the coal and poor draft.

COAL.

Steaming Qualities of Coal.—In this connection the values of the different characters of coal that can be obtained for a given plant should be understood in order that the grate surface and draft may be arranged to give the maximum results in the combustion of this coal. Coal consists of moisture, ash and combustible. The moisture may be surface moisture, due to exposure, or may be inherent moisture, which exists in comparatively dry coal and is only expelled on heating to a temperature of 240 degs. Fahr. The surface moisture can be evaporated by exposure to dry air or storing in dry places. The quantity of the natural moisture should be less than 1 per cent in anthracite but is as high as 14 per cent in some Illinois coal. It depreciates the heating value of coal to heat it for drying, especially where there is iron pyrites present in the coal; coal dried by artificial methods will again absorb moisture on being exposed for a long time to the atmosphere. Where moist coal is used in a boiler, additional capacity has to be added to the grate surface in order to develop enough heat to raise this moisture to the temperature of the flue gases or uptake, and, as a rule, the thermal value of the coal is reduced by this amount.

Where the furnace is properly adapted for the coal to be burned, the ash in the coal comes from two sources; one, the non-combustible portion, consisting of the non-combustible minerals formed in the original vegetable growths, the other, clays, slates or iron pyrites, which may appear in seams through the coal deposits. The ash element in the coal can be greatly reduced in quantity by carefully mining and sorting the coal at the breakers. Coals high in ash require that the fires be handled more frequently in the furnace, and for a given combustion of coal larger grate areas should be used. Some of the low grade coals require the building of a furnace external to the boilers in order to obtain sufficient area.

The value of a coal is determined by its combustible matter, and some stations have bought coal on condition that only the combustible matter should be paid for, subtracting from the weight of coal that of the unconsumed ash. Coals high in sulphur cause trouble in the furnace by the formation of clinkers on the grate bars, the sulphur combining with silicate; and earths in the ash form a fusible slag or glass, which interferes with the air supply and diminishes the coal burning capacity of the grate surface.

Coals are classified according to their general character into anthracite, semi-anthracite, semi-bituminous and bituminous. Anthracites are those coals which contain less than 7½ per cent volatile matter in the combustible, being low in moisture. The smaller sized coals go under the name of chestnut, pea, rice, buckwheat, barley and screenings; and, generally speaking, the smaller the size of coal the greater per cent of ash it contains. The analysis from one mine gives the following ratios: Egg screen, 2½ in.–1¾ in. 88.49 free carbon, 5.66 ash; stove 1¾ to 1¼ 83.67 f. c., 10.17 a.; chestnut, 1¼ ins.-¾ in. 80.72 f. c., 11.67 a.; pea, ¾ in.-½ in. 79.05 f. c, 14.66 a.; buckwheat, ½ in.-¼ in. 76.92 f. c., 16.62 a. The semi-anthracite and semi-bituminous coals contain 12½ per cent to 25 per cent volatile matter in the combustible, usually run low in moisture, ash and sulphur, and have high heating value per pound of combustible. These form the best steaming coals in the United States, and can be burned at a higher rate on a grate surface without clinker.

Bituminous coals contain 25 per cent to 50 per cent volatile matter, and vary considerably with the coal-bearing areas in the United States, west of the Alleghany Mts. In a general way the volatile matter increases as they go westward and northward of the Alleghany Mts. The percentage of moisture also increases as they go westward ranging from 2 per cent near Pittsburg to 14 per cent in some of the Illinois coals.

From a chemical analysis of coal its heating value may be calculated within a limit of error of 2 per cent by the application of DeLong's Formula which follows. Here C stands for carbon, H for hydrogen, O for oxygen, and S for sulphur in the coal. The heat units per pound =

$$.01 \left[14{,}600\ C + 62{,}000 \left(H - \frac{O}{8} \right) + 4000\ S \right]$$

The proximate analysis of coal is also largely used, giving the volatile matter, fixed carbon and ash in the coal. The probable heating value can be figured within an error of 3 per cent by the use of the following table:

APPROXIMATE HEATING VALUE OF THE COMBUSTIBLE PORTION OF COAL.

Composition.		Heating Value per lb.	Equivalent Water Evaporated from and at 212 degs. per lb. of Combustible.
Fixed Carbon.	Volatile Matter.	Heat Units.	
97	3	14,940	15.47
94	6	15,210	15.76
90	10	15,480	16.03
87	13	15,660	16.21
80	20	15,840	16.40
72	28	15,660	16.21
68	32	15,480	16.03
63	37	15,120	15.65
60	40	14,760	15.28
57	43	14,220	14.73
55	45	13,860	14.35
53	47	13,320	13.79
51	49	12,420	12.86

The practical way that operators of central stations can exactly determine this matter for themselves, under their own conditions, is to secure sufficient coal for several days' run and burn this coal under average practical conditions, thus finding the output in watts for the weight of coal or the cost of coal per kw output.

In changing from one coal to another, especially in the case of the different sizes of pea coal or from hard to soft coal, the grate or furnace may not be properly constructed to utilize to the best advantage the heat units in the new coal. The unconsumed carbon in the ash, the temperature of the uptake, the smoke issuing from the chimney and the draft should all be taken into consideration when testing a new coal in order that the test be carried on under conditions giving most accurate results. The fireman is often puzzled at first to get the best results from a change in the grade of coal. Unless these points are carefully watched in a coal test of this kind, a coal which has capabilities of producing greater output for the same cost may not have a fair trial; and this is especially so in changing from anthracite to bituminous coal, as the furnace for one is unsuitable for the other, these two coals requiring considerable difference in furnace construction.

Below is a table giving heating values of some well-known coals in heat units per pound of combustible and the equivalent, evaporation from and at 212 degs. Fahr.

HEATING VALUES AND EQUIVALENT EVAPORATION OF VARIOUS KINDS OF COAL.

	Heat Units per pound combustible.	Equivalent evaporation from and at 212°.
Anthracite, Pa	14,900	15.42
Semi-anthracite, Loyalsock and Bernice, Pa.	15,500	16.05
Semi-bituminous, Broad Top, Clearfield, Cambria, and Somerset, Pa.; Cumberland, Md., New River, W, Va., and Pocahontas, Va.	15,700 min. 15,800 max.	
Close average	15,750 aver.	16.30
Bituminous, Connellsville, Pa	15,300	15.84
Youghiogheny, Pa	15,000	15.53
Jefferson, Pa	15,200	
Pittsburg, Pa	14,800	15.32
Brier Hill, Ohio	14,300	
Upper Freeport Seam, Pa. & O	14,800	15.32
Vanderpool, Ky	14,400	
Middle Kittanning Seam, Pa	14,500	15.01
Thacker, W. Va	15,200	15.74
Jackson Co., O	14,600	15.11
Hocking Valley, O	14,200	14.70
Big Muddy, Ill	14,700	15,22
Streator, Ill	14,300	14.80
Mt. Ollive, Ill	13,800	14.29
Lignites, Ia., Wyoming, Utah, Oregon	11,000 to 12,900	11.39 to 13.35

With a boiler properly designed in all its proportions it is found that the maximum economy is obtained when the boiler is driven at an equivalent rate of evaporation of three pounds of water from and at 212 degs. per hour per square foot of heating surface. When the evaporation falls below this rate, the radiation and other boiler losses rapidly grow in the percentage of the output as they are in a large degree constants.

As a rule, the economy falls with a rapid rate of driving the boiler, yet among the different boilers, changes in the economy for the different rates of evaporation even with the same kind of coal, will not follow the same curve between the water evaporated per square foot of heating surface and the pounds of water evaporated per pound of coal. It may, however, be expected that the evaporation per pound of coal will be approximately 15 per cent less when the evaporation is forced up to 6 lbs. of water per square foot of heating surface than when it is at the average rate of maximum economy of 3 lbs. per square foot of heating surface. But the above general rule must be used with considerable allowance. A Babcock & Wilcox boiler in the power station of the Hestonville, Mantua & Fairmount Park R. R., Philadelphia, Pa., shows an evaporation of 6.34 lbs. of water per square foot of heating surface, and the water evaporated per pound of combustible was 10.97; on the Staten Island Electric R. R. Co., New Brighton, Staten Island, the same type of boiler had an evaporation of 2.66 lbs. of water per square foot of heating surface with 11.78 lbs. of water per pound of combustible. The ratio of heating surface to grate surface in the first case was 46.87, and in the second, 60.28.

The grate surface of a boiler can be roughly assumed to be ⅕ sq. ft. per hp-hour. The table given herewith of several types of boilers shows the grate surface used by different makers per hp-hour; it will be noticed that the larger the boiler unit, the smaller the surface required to produce a hp-hour. The heating surface figure is given as 11.5 sq. ft. per hp-hour.

GRATE SURFACE PER HORSE-POWER HOUR.

Horse-power of Boiler.	Type of Boiler. Heine. Grate Surface per hp-hour.	Type of Boiler. Babcock & Wilcox. Grate Surface per hp-hour.	Type of Boiler. Clonbrock. Grate Surface per hp-hour.
150	.186	.244	.32
200	.185	.222	.25
250	.176	.204	.24
300	.182	......	.213
360	.164	......	......
400	......	......	.1925
600	......	......	.183
1000	......	......	.171

The ratio of the heating surface to the grate surface varies largely in boilers of different types. Reports of tests on some thirty Babcock & Wilcox boilers show a variation in ratio of from 62 to 37: 1 of the heating surface to the grate surface. The Stirling boiler shows a variation of 76:1 on a 600 hp. boiler, 44.7:1 on a 250 hp. boiler, and 37:1 on a 125 hp. boiler; the Climax varies from 51 to 33:1 ratio.

For further data and methods of conducting boiler tests see pages 77 to 85.

TYPES OF BOILERS.

The Fire-Tube Boiler.—This boiler is manufactured largely throughout the country by boiler manufacturers, the shell ranging from 72 ins. to 54 ins. in diameter. The table of dimensions below gives the practical, standard proportions for one of these boilers.

Following is a report of a test of horizontal return tubular boiler for New Bedford & Fair Haven Traction Co., New Bedford Mass. Test made by H. L. Butler, M. E., of Wm. Sellers & Co., Philadelphia.

Dimensions of Boilers on which test was made.

Diameter of Shell	72 ins.
Length of Shell and Tubes	17 ft. 6 ins.
Number of Tubes	132-3 ins. diam.
Area of Heating Surface	1877.68 sq. ft.
" " Grate Surface	36 " "
" through Tubes	5.55 " "
Ratio of Heating Surface to Grate Suıface	52 to 1
" " Grate Surface to Tnbe Area	6.4 to 1

Stack 48 ins. Dia. 90 ft. high above Grates.
Boilers set in Pairs. One Boiler tested, the other banked.

Report of Test.

Manner of Start and Stop	Running
Kind of Run	Continuous
Duration	11 Hours
Quality of Coal used, "Pocahontas," bituminous, run of mine.	
Coal Consumed (11 hours)	4556 lbs.
" " (per hour)	414.18 lbs.
" per square foot of Grate per hour	11.5 lbs.
Percentage of Ash { Ashes not considered, non-combustible reduced to powder, weighing not more than 3 lbs. for whole run, Everything practically consumed. }	.00
Percentage of Moisture in Coal	6.66 per cent
Combustible used in (11 hrs)	4252.57 lbs.
" " (per hour)	386.59 "
Water Evaporated (11 hours)	52,236.5 "
" " (per hour)	4748.77 "
" " per square foot of Heating Surface	2.52 "
" " per pound Commercial Coal	11.46 "
" " " " Combustible	12.28 "
" " " " " from and at 212 degs	13.23 "
Boiler Pressure (average gage)	130 "
Temperature of Water before entering Heater	38 degs.
" " Feed Water before entering Boiler	180.93 "
" " Escaping Gases, Maximum	402 "
" " " " Minimum	320 "
Percentage of Moisture in Steam	1.3 per cent.

The heating surface in different types of this boiler, varies somewhat with the setting; but the test by H. L. Butler on this type of boiler, manufactured by the Harrisburg Foundry & Machine works, with the Weitmeyer furnace which consists essentially of very carefully proportioned parts of grate, flue areas and drafts, gives the results shown in the table above.

The value of the special setting in this boiler is in carrying the draft from the back of the boiler setting, passing under an apron in the combustion chamber and under the bridge wall, to the coal, in this way raising the initial temperature of the draft and improving the conditions of combustion. Fig. 168 shows the setting for the horizontal tubular boiler as designed by the Hartford Steam Inspection & Insurance Company.

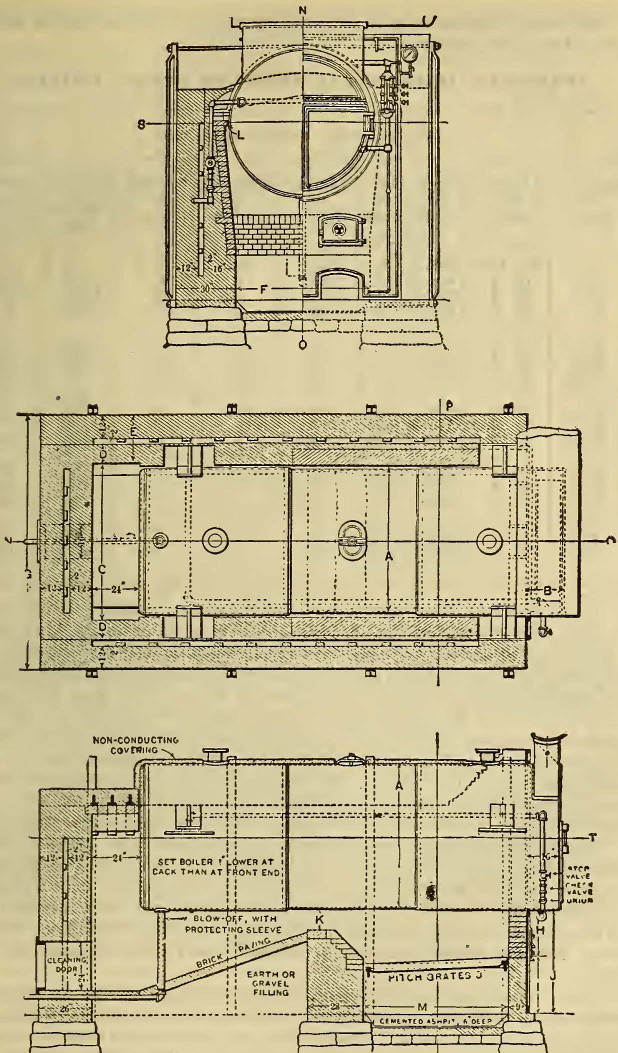


Fig. 168—Hartford Steam Inspection and Insurance Company's Setting.

The table below can be used for installing this type of boiler, which may be used in the smaller stations.

STANDARD HORIZONTAL TUBULAR STEAM BOILER.

TABLE OF SIZES, PROPORTIONS, ETC.

Diameter of Shell.	Length of Shell.	Gage of Shell.	Gage of Head.	Number of Tubes.	Diameter of Tubes.	Length of Tubes.	Sq. Ft. of Heating Surface.	Nominal Horse Power.
Ins.	Ft. Ins.	Ins.	Ins.		Ins.	Ft.		
72	19 4	3-8	1-2	80	4	18	1,500	100
66	18 4	3-8	1-2	74	3½	17	1,350	90
60	18 3	3-8	1-2	78	3	17	1,200	80
60	17 3	3-8	1-2	76	3	16	1,125	75
60	16 3	3 8	1-2	77	3	15	1,050	70
60	16 3	3-8	1-2	70	3	15	975	65
60	16 3	3-8	1-2	64	3	15	900	60
54	17 3	5-16	7-16	60	3	16	900	50
54	17 3	5-16	7-16	56	3	16	825	55
54	16 3	5-16	7-16	52	3	15	750	50
54	16 3	5-16	7-16	46	3	15	675	45
54	16 3	5-16	7-16	40	3	15	600	40
48	17 2	5-16	7-16	50	3	16	750	50
48	16 2	5-16	7-16	48	3	15	675	45

These drawings show the projecting front setting, which is preferable to the flush front, for it costs less for repairs and no more to install. In building a double wall to the boiler setting, bricks from the outer wall should project and just touch the inner one; this allows the inner wall to expand without fracturing the retaining wall. The outer wall should be 12 ins., both sides and rear, in every case, and the distance between the boiler and inner rear wall, 24 ins. The boiler walls are tied together by rods passing from wall to wall across the setting and secured to the top and bottom of ribbed or cast-iron plates as shown in the engraving. In no case should lime mortar be used in any brick work or in masonry that touches the iron, for the heat will produce a chemical action between the lime and iron which will severely corrode the latter and weaken it.

The boiler is ordinarily mounted upon the settting on iron plates set on the side walls resting on cast-iron brackets or lugs riveted to the sides of the boiler; the back lug does not rest directly on the plate but on iron rolls which are inserted between the back lug and plate. Where there are more than four lugs all lugs should have rollers except the front lugs which rest directly on the iron plate. The rear end of the boiler is ordinarily set 1 in. lower than the front end.

In order to reduce the high tensile strength and large volume of water contained in the horizontal tubular boilers, a number of forms have been developed during the past twenty years. These boilers are designed to increase the coal steaming capacity, the circulation of water and to confine the deposit from the water, both mineral and suspended impurities, to locations where they will not be acted on by intense heat and readily blown out when cleaning or repairing.

MEASUREMENTS FOR THE SETTING OF HORIZONTAL TUBULAR BOILERS.

A Diameter of Boiler.	B Curtain Sheet.	C Width of Flame Bed.	D Inside Side Walls at Center of Boiler.	E Total Thickness of Side Walls at Center Line of Boiler.	F Width of Furnace.	G Width of Setting.	H Top of Front end of Grate to Bottom of Boiler.	I Top of Front end of Grate to Floor Level.	J Bottom of Boiler to Floor Level.	K Bottom of Boiler to Top of Bridge Wall.	L Air Space at Sides of Boiler at Center Line.	M Length of Grate Recommended.	A Diameter of Boiler.
48	12	56	9	23	42	102	24	24	48	9	4	48	48
50	14	58	9	23	44	104	24	24	48	9	4	50	50
52	14	60	9	23	46	106	24	24	48	9	4	52	52
54	14	62	9	23	48	108	24	24	48	9	4	54	54
56	14	64	9	23	50	110	24	24	48	9	4	56	56
58	14	66	9	23	52	112	24	24	48	9	4	58	58
60	14	68	9	23	54	114	24	24	48	9	4	60	60
62	16	68	10	24	56	116	28	24	52	10	3	62	62
64	16	70	10	24	58	118	28	24	52	10	3	64	64
66	16	72	10	24	60	120	28	24	52	10	3	66	66
68	16	74	10	24	62	122	28	24	52	10	3	68	68
70	16	76	10	24	64	124	28	24	52	10	3	70	70
72	16	78	10	24	66	126	28	24	52	10	3	72	72

Water-Tube Boilers: General Construction.—The points that are gained by this form of construction are as follows: a mud drum to receive all impurities, a large water surface for the disengagement of the steam from the water, and thorough circulation of the water throughout the boiler, so as to maintain all parts at one temperature as nearly as possible.

For lessening danger the water surface is divided into sections so arranged that should any one part give out no general explosion would occur. The construction is so arranged that it will bring as few joints as possible exposed to the direct action of the fire, reducing the liability of internal strains thrown on the boiler by unequal expansion. The heating surfaces are located as nearly as possible at right angles to the currents of heated gases so as to break up the currents and extract as much available heat from them as possible.

The designers of this type of boiler also leave ample openings so the water tubes can be cleaned both externally and internally.

The Babcock & Wilcox Boiler.—This type of boiler is shown in Fig. 169. The boiler is composed of sections made up of 4-in. wrought iron tubes expanded into headers, and connected into a steam and water drum by 4-in. tubes expanded into upper ends of headers, and into wrought-steel cross boxes on under side of drum.

The mud drum, placed at the lowest point of the structure, is connected by 4-in. nipples to the bottom ends of the rear headers. The tube and nipple connections between all parts are made by expanded joints.

LIST OF STANDARD SIZES OF BABCOCK & WILCOX PATENT WATER TUBE BOILERS:

W. I. F. TYPE.

No.	H. P. Actual.	Minimum Evaporation per Hour.	Construction. Tubes. Wide.	Tubes. High.	Tubes. Long.	Drum. No.	Drum. Diam.	Drum. Long.	Approximate Total Weight. (Packed.)	Space Occupied. (Including Brickwork.) Length.	Space Occupied. Width.	Space Occupied. Height.	Number of Bricks Required. Common.	Number of Bricks Required. Fire	Steam Stop Valve. Diam.	Furnace. Width.	Furnace. Length.	Furnace. Area.	Heating Surface for Coal.
		lb.					in.	ft. in.	tons.	ft. in.	ft. in.	ft. in.			in.	ft. in.	ft. in.	sq. ft.	sq. ft.
15	106	3180	6	9	18	1	36	23 7	11¼	23 0	6 10	13 6¼	12600	2500	5	3 10	6 0	23.00	1218
16	110	3300	7	8	18	1	36	23 7	11¾	23 0	7 5	13 0¼	12600	2500	5	4 5	6 0	26.50	1265
17	123	3690	7	9	18	1	36	23 7	12½	23 0	7 5	13 6¼	13000	2500	5	4 5	6 0	26.50	1411
18	124	3720	7	9	18	1	42	23 7	13	23 0	7 5	14 1½	13000	2600	5	4 5	6 0	26.50	1426
19	140	4200	8	9	18	1	42	23 7	14¼	23 0	8 0	14 0½	13000	2600	6	5 0	6 0	30.00	1619
20	152	4560	12	7	16	2	36	21 4	17¼	21 0	10 4	12 6¼	13200	2600	6	7 4	5 0	36.65	1741
21	160	4770	9	9	18	1	48	23 7	17	23 0	8 7	14 6½	13000	2600	6	5 7	6 0	33.50	1827
22	172	5160	12	8	16	2	36	21 4	18½	21 0	10 4	13 0¼	13200	2700	6	7 4	5 0	36.65	1966
23	192	5760	12	9	16	2	36	21 4	19½	21 0	10 4	13 6¼	13500	2700	6	7 4	6 0	44.00	2197
24	212	6360	12	9	18	2	36	23 7	20¾	23 0	10 4	13 6¼	13500	2800	7	7 4	6 0	44.00	2437
25	220	6600	14	8	18	2	36	23 7	21¾	23 0	11 6	13 0¼	14000	3000	7	8 6	6 0	51.00	2531
26	246	7380	14	9	18	2	36	23 7	22½	23 0	11 6	13 6½	14000	3000	7	8 6	6 0	51.00	2823
27	248	7440	14	9	18	2	42	23 7	24¼	23 0	11 6	14 0½	14000	3600	7	8 6	6 0	51.00	2852

The boiler is suspended at front and rear from wrought iron supporting frames, entirely independent of the setting, to allow for contraction and expansion without straining either the boiler or the brickwork, and to allow of repairs to, or renewal of, the latter without disturbing the boiler or its connections.

Steam is taken from a dry pipe perforated on top side and connected into a flanged steam opening on top of drum. When two or more steam drums are used on one boiler, the drums are connected by a balance pipe upon which the safety valves are mounted, and a cross pipe for main steam valve.

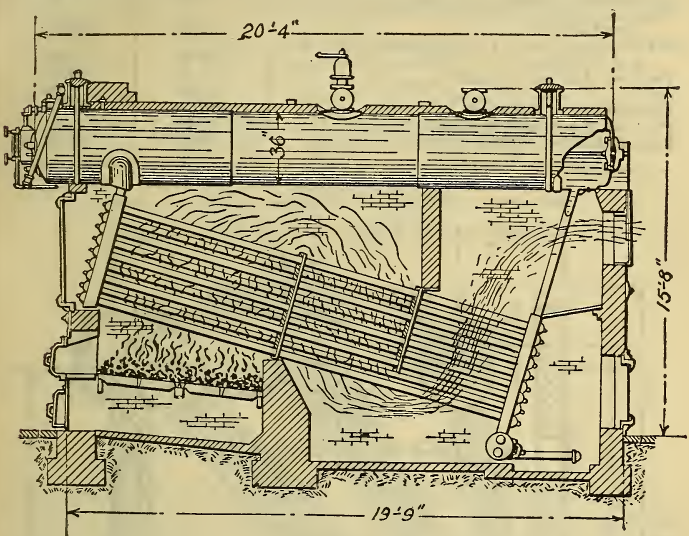


FIG. 169—BABCOCK & WILCOX BOILER.

The hand holes are closed on the outside by a cap which is held in position by a forged steel clamp closing the hand-hole opening from the inside and secured by a bolt.

The mud drum is 12 ins. in diameter and of proper length to be connected with all of the sections in the boiler by means of nipples expanded into seats. It is tapped for blow-off connections on its rear side, and furnished with hand-holes for cleaning.

The space occupied by a boiler of 250 hp. is shown in Fig. 169, and the sizes of a boiler of the W. I. F. type from 106 hp. to 248 hp. are given in the table on page 176. These dimensions should only be used for approximately locating these boilers; a space should be left of at least 19 ft. in front of the boiler so the tubes can be withdrawn in case of repairs.

The table on the following page gives a test on two Babcock & Wilcox boilers taken from their catalogue on railway plants.

OWNER OF PLANT WHERE TEST WAS MADE.	Hestonville, Mantua & Fairmount Pk. R.R. Phila., Pa.	Staten Island Elec. R. R. Co. New Brighton, Staten Island.
Engineer conducting test	J. J. DeKinder	W. N. Sheaff
Kind of coal	Henrietta, Pa.	Victor, Pa.
Date	Mar. 29, 1895	May, 28, 1897
Duration, hours	9.50	10
Coal burned per sq. ft. of grate per hour	28.92	15.17
Water evaporated per sq. ft. of heating surface per hour from and at 212 degs	6.34	2.66
Water evaporated from and at 212 degs. per pound of coal	10.28	10.70
Water evaporated per pound combustible from and at 212 degs	10.97	11.78
Per cent of refuse in coal	6.32	9.13
Draft	.87	.48
Temperature of flue gases	750°	485°
Per cent of moisture in steam	.12	....
Ratio of heating surface to grate	46.87	60.28

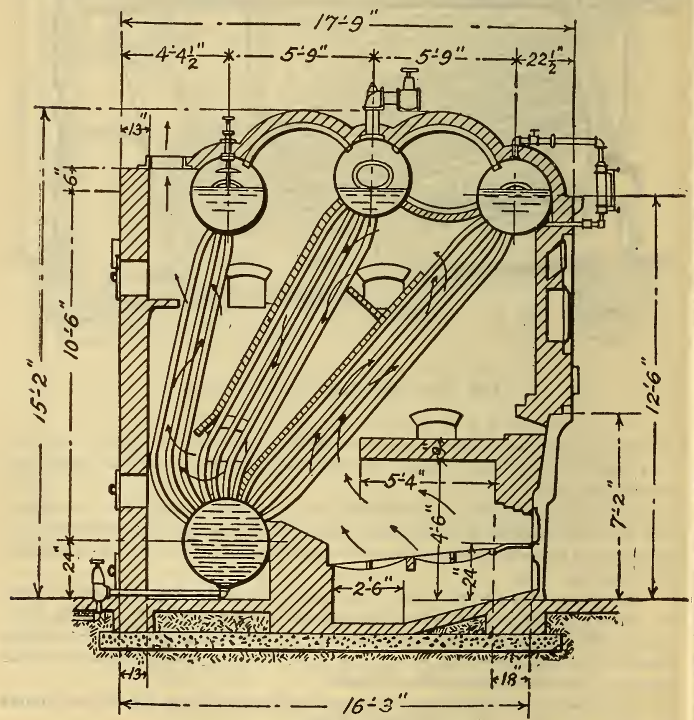


FIG. 170—STIRLING WATER TUBE BOILER.

Stirling Water-Tube Safety Boiler,—The boiler consists, briefly, of three upper or steam drums, and one lower or mud drum, all connected together by means of tubes, which are bent slightly, so as to allow them to enter the drums normal to their surfaces. See Fig. 170. All the upper or steam drums are connected by steam circulating tubes, but the front and middle drums only are connected by water circulating tubes. The tubes used are 3¼ ins. in diameter, and are made of lap-welded, mild steel.

The circulation of the hot water is between the two forward drums and the lower mud drum, the feed water being introduced into the third drum. See Fig.

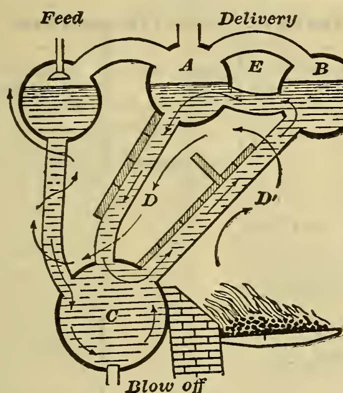


FIG. 171—CIRCULATION IN STIRLING BOILER.

171 for path of circulating water. The equalizer pipes connecting the drums introduce steam into the middle drum, which is used as a heater for the numerous pipe sections. In order to produce dry steam the end of the steam pipe terminates in a T inside the middle drum to which are secured pipes, near the top of the drum and paralleling it, in which are cut slots in order to throttle the steam, so

TABLE OF STIRLING BOILERS.

TYPE.	HEIGHT.	DEPTH.	WIDTH FOR EACH HP.
Class A	18′ – 9″	16′ - 0″	.056′
B	12′ – 0″	14′ - 0″	.087′
E	15′ – 2″	16′ – 3″	.065′
F	20 – 7″	16′ – 9″	.043′
G	20′ – 5½″	19′ – 7″	.056′
H	18′ – 3″	17′ - 6″	.051′
I	21′ – 3″	19′ - 6″	.056′
K	21′ –10″	17′ – 7″	.04 ′
L	22′ - 4″	15′ – 3″	.036′

that dry steam will be produced for sudden steam demands; this is especially used for railway work where the steam demands will be frequently of this nature. In setting this boiler, it is sustained independently of the brickwork surrounding it. The three upper steam drums are supported by wrought iron beams resting on wrought iron columns, while the mud drum is suspended and left free to allow for contraction and expansion. The dimensions of the Stirling boiler are given in the table on page 179.

The Stirling boiler is built to meet the varying requirements of height, width and depth and the different types lettered as in the table. Some tests made on these boilers are given below.

TESTS ON STIRLING BOILERS.

Location.	Lehigh Valley Trac. Co., Allentown, Pa.	Union Ry. Co., Providence, R. I.	Lindell Ry. Co., St. Louis, Mo.
Engineer	P. Hansen	Thos. Evans	W. H. Bryan
Rating	600	250	300
Duration test	10	9.7	9
Temperature of feed	191.8	66	47
Evaporation per lb. coal from and at 212 degs	8.47	10.57	7.82
Evaporation per lb. combustible from and at 212 degrees	11.27	11.61	8.92
Coal consumed per square foot grate per hour	9.91	14.8	....
Draft	.3	.75	.77
Moisture in steam per cent	....	1.75	.14
Temp. of escaping gases	358	308	448
Per cent developed above rating	....	6	15
Below rating	1.5	....	....
Kind of fuel	Buckwheat	Cumberland	Illinois Lump

The Morrin Climax Water-Tube Boiler is manufactured by the Clonbrock Steam Boiler Company. Fig. 172 shows the general construction. It consists of a vertical cylinder and loop-like tubes, which form the principal heating surface, extending the entire length of the boiler. The main cylinder shell, *A*, is constructed similarly to any cylindrical boiler shell, aud is made perfectly steam tight as well as strong enough to resist internal pressure. It is provided on top with a manhole plate. The extremities of the loop-like tubes extend and are expanded into the cylinder, *A*, forming a steam tight connection; these tubes re-enter the cylinder about 18 ins. above their initial entrance. As the boiler increases in size, the water and steam spaces increase in the same ratio.

In some boilers the feed water has been introduced through a spiral pipe located above the loop tubes, and used as a water heater for the boiler. The fire box is annular in form, and enclosed in a casing of iron, which is bolted together in segmental sections and lined with fire brick. Three or more fire doors are provided for the boiler depending upon its size. According to the data given by the Clonbrock Steam Boiler Company, the heating surface of its boilers evaporates 6 lbs. of water per square foot of heating surface per hour with a rate of combustion oi 12½ lbs. of coal per square foot of grate per hour. The table herewith gives the sizes of these boilers and the spaces they occupy.

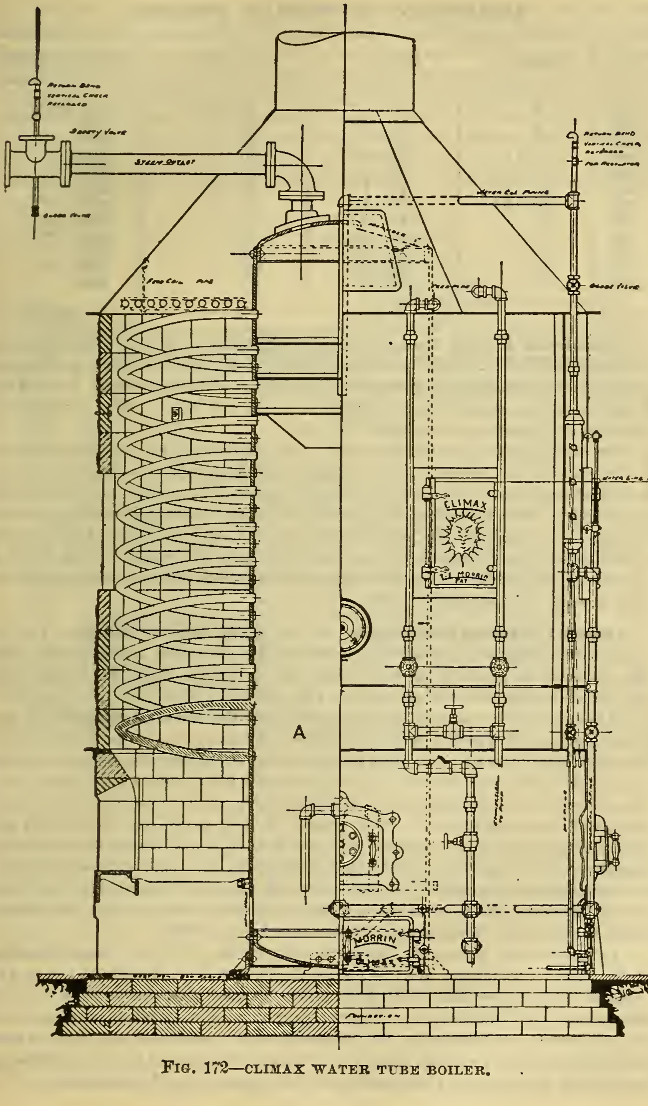


FIG. 172—CLIMAX WATER TUBE BOILER.

DIMENSIONS OF CLIMAX BOILERS.

HP.	Diameter.	Height.	Grate Surface.	Heating Surface.
100	8′	14′ 2″	34 sq. ft.	1025 sq. ft.
125	9′	17′ 6″	42 "	1280 "
150	10′	18′	48 "	1675 "
200	10′ 3″	19′ 10″	50 "	2000 "
250	10′ 11″	21′ 6″	60 "	2500 "
300	11′ 2″	23′ 1″	64 "	3000 "
350	11′ 6″	27′ 2″	69 "	3475 "
400	12′	27′ 6″	77 "	3650 "
500	12′ 8″	31′ 4½″	89 "	4550 "
600	14′	33′ 6″	110 "	5600 "
800	15′	36′ 10″	128 "	7000 "
1000	17′	42′ 8′	171 "	9200 "

Abendroth & Root Boilers.—The construction of this boiler provides for the circulation of the heated gases, not only among the tubes, but around the overhead steam and water drums; the heated gases also circulate around the cross steam drum, maintaining the temperature of the steam. The general construction of this boiler is shown in Fig. 173.

The setting is peculiar to this boiler. The entire weight on the front ends of the tubes and drums rests on a swung beam; the weight is supported from underneath and the beam is supported by rods attached to the top of the front setting of the boiler. The tubes forming the heating surface are connected together at the ends by a U-pipe, which joins the ends of two adjacent tubes. Each vertical set of tubes starts from a header, and each pair of vertical tubes enters a separate steam header on top and these various steam headers enter one equalizing header, as shown in Fig. 173.

General Information.—Boiler setting plans, specially designed for the boiler to be installed, are usually furnished by the boiler manufacturer; and these should be adhered to closely, as any deviation from this design may seriously interfere with the guaranteed efficiency.

When the boiler has been completely set, and the lime mortar and fire-clay luting has hardened so that a knife blade will not penetrate it more than $\frac{1}{16}$ in., and not sooner than 12 hours after the masons have finished, the boiler should be slowly filled with cold water up to the high water gage; then a slow fire of shavings and wood may be built on the grate surface, covering not more than one-quarter of the grate surface. This should be kept going until the boiler and setting are warmed up; the safety valve or header, should be wide open during this firing. When steam issues from the boiler, the openings may be closed and the steam pressure gradually raised. A great many boiler settings have been ruined by heating them up to quickly; 48 hours should be required for a 200-hp. water-tube boiler to reach a temperature of 212 degs. Fahr.

Pyrometers for measuring flue temperatures also aid in the proper handling of the dampers and draft, but this temperature of uptake cannot be taken as a criterion of firing economy; for with a slow fire, the flue temperature and efficiency may both fall together. Where steam blowers are used, these may reduce the temperature of the uptake, but, due to the additional heat required to raise the temperature of the draft moisture, the temperature may be lower in the uptake, while the heat units lost passing up the chimney may be increased.

Grates are made stationary, consisting usually of V-shaped cast-iron bars; the air space between the bars is generally about 25 per cent of the grate area, but this is less with screenings and coal smaller than pea. The bars are usually placed parallel to the furnace sides so the slicing bar and poker can readily clean between the bars. These grate bars are supported on transverse beams, which are secured to the sides of the furnace. There are a number of forms of shaking and dumping grates to reduce the time required to clean the fires, and assist in disengaging the ash from the burning fire bed. Their construction embodies a pivoted section of a grate bar, movable by a handle projecting from the boiler; in some forms they are arranged so that by further pulling out this handle, the grates are tipped sufficiently to dump the fire. The best height for grates is 30 ins. above the floor level. Where hot air is used for draft or in down draft furnaces, these grate bars are hollow and water kept circulating through them to keep them from yielding or melting under the increased temperature.

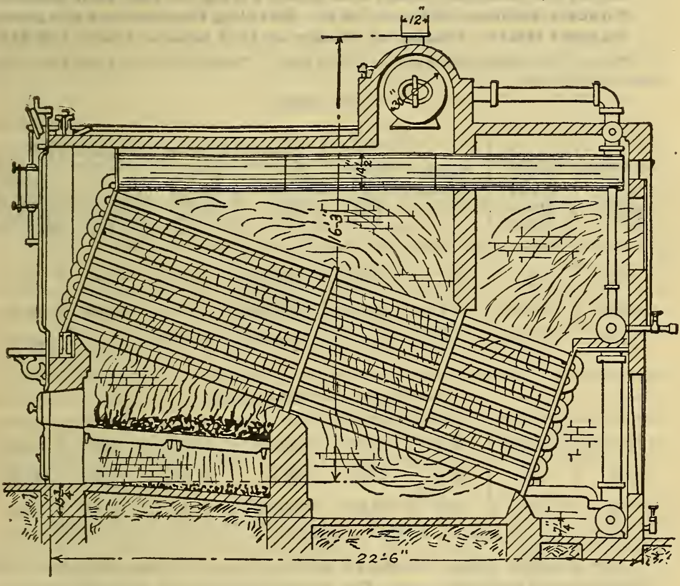


FIG. 173—ABENDROTH & ROOT BOILER.

MECHANICAL STOKERS AND TRAVELING GRATES.

Here the grate bars are not made continuous and solid, but are carried forward by proper mechanism away from the fire door, where coal is automatically fed with a variable depth on the traveling grate from a hopper. The speed of driving this grate is under control; the coal should be completely burned before it reaches the end of its journey through the furnace. Such a grate is practically self cleaning with a coal that does not slag badly. Mechanical stokers do not handle well either a very hard variety of anthracite nor a bituminous which cakes and melts badly; but with the exception of these two classes of coal, the mechanical stoker has proven a coal and labor saving device in a number of railway plants. In some of the types of mechanical stokers, the rate of feeding the coal is automatically controlled by the steam pressure of the boiler.

Record of Six Tests to Determine the Comparative Economy of the Roney Mechanical Stoker and Hand Firing on Hartford Return-Tubular Boilers, 60 ins. x 20 ft. Burning Cumberland Coal with Natural Draft. Rating of Boiler at 12.5 Square Feet. 105 HP.

NOTE.—The same man fired on all six tests. First three tests, hand fired; last three tests, stoker.

Duration of Test. Hours.	Temp. of Feed Water Degs. Fahr.	Steam Pressure. Lbs.	Total Coal plus Wood at 40%. Lbs.	Total Water Evaporated. Lbs.	Evaporation per lb. dry Coal, actual. Lbs.	Evaporation per lb. dry Coal from & at 212°. Lbs.	HP. developed above rating of Boiler. Per Cent
HAND FIRED.							
123.5	145.7	107.5	134,459	1,256,249	9.34	10.36	5.84
132.0	143.2	104.6	135,338	1,270,758	9.39	10.44	13.52
64.25	152.2	66.1	31,214	310,966	10.02	11.00	68.00
MECHANICAL STOKER FIRED.							
65.5	145.4	63.1	28,121	288,781	10.81	11.89	54.65
64.5	146.0	68.0	29,794	303,887	11.06	12.25	66.68
65.5	145.2	65.2	29,000	320,034	11.35	12.54	84.26

The American Stoker Company's mechanical stoker burns effectively both bituminous and anthracite coal. The mechanism is simple and easily operated and under the combustion principles used in its construction, it attains a more economical use of coal than by hand firing. The gases leaving the chimney are totally consumed, leaving no free carbon.

In tests made in Cleveland, Ohio, with mechanical furnaces, the poorest of the cheap coals consumed was 4.93 lbs. per hp-hour. The economy of the cheap coal mechanically fired over that for the high priced coal, hand fired, shows an earning power of capital investment equal to 30 per cent. Data of tests on slack coal hand fired, and like coal mechanically fired show the following results: the economy favored mechanical firing 20 per cent plus the factors of lessened labor, cost in fire room and smokelessness.

MANAGEMENT OF BOILERS.

Firing.—In firing hard coal the grate bars should be such as to allow the least possible amount of unburnt carbon or coals to drop through before they are fully consumed, and yet sufficient draft area to consume the coal. The most economical firing, where buckwheat, pea or rice coal is handled and where the coal is not very high in ash, is to fire uniformly with a bed of coals not deeper than 3 ins.

The skill of the fireman is shown by his ability to maintain the whole fire surface at a uniform color or temperature; dark spots or thin fire in spots indicate that he has not the control of the shovel necessary to distribute the coal exactly where required for uniform combustion. A poor fireman will show bad corners where ash is allowed to accumulate, in this way reducing the available combustion surface of the furnace. Dark spots indicate poor combustion or too thick a fire, and open spots will decrease the draft possible to maintain. It requires less skill to fire a heavy fire ranging from 5 ins. to 6 ins. thick, but the draft will be throttled and not sufficient air can pass through the fire bed to obtain total combustion, and the gases will pass off as CO instead of CO_2, not combining with the last molecule of oxygen which increases the temperature of combustion considerably.

It requires less labor and attention to maintain thick fires than thin ones, but the coal cost is larger for the same amount of water evaporated under the same boiler. It also should be borne in mind that a high draft gage does not indicate the best firing conditions, for the more the fire on the furnace throttles the draft, the higher it is possible for the draft gage to show, but the volume of air passing may not be sufficient for complete combustion. A thin fire will require less slicing than a thick one, and there will be found less unconsumed carbon in the ash as a rule. Cleaning the fires ought not to be done oftener than necessary to maintain the best firing conditions, and the fire should be jockied into condition to meet increasing loads on the station, and generally cleaned after heavy loads.

From experience in testing and inspection of power stations it is found that there is no point in the station plant where more money can be saved than in the proper burning of coal. A poor fireman can waste many times his salary per year by lack of intelligent attention to handling the fire, Merit systems have been established in some plants, which rebate to the fireman a percentage of his savings in coal costs.

Soft coal firing is generally done by first firing near the door on the deadplate and allowing the heat of the fire to gradually coke the coal, expelling from it the volatile part of the combustible. This is coked here and gradually shoved back to make room for new coal, and when it reaches the end of the grate it is almost entirely consumed. Lumps larger than 4 ins. in diameter should be broken up in order that this coking process may be properly carried on.

Soft coal fires reach their maximum temperature at a more distant point in the draft than hard coal fires. It is necessary for the surfaces, over which the gases pass to be of higher temperature, in order that the unconsumed carbon may be raised to sufficient temperature to combine with the oxygen and not pass out in the form of smoke.

The furnace arrangements should be such that the high temperature gases will not impinge against portions of the boiler unsuited to withstand them. The smoke passing out of the chimney from a soft coal fire is a criterion of the efficiency of its combustion.

There are a number of arrangements for the fireman, by which he can determine the completeness of combustion. One is the Gas Composimeter, which indicates the percentage of CO carried off with the gases in the flue, and registers automatically the amount of this gas present. The draft and dampers can be regulated to keep the carbon dioxide as high as possible, and aids in the correct firing of the boiler.

Care of Boilers.—The following rules are compiled from those issued by various Boiler Insurance Companies in this country and Europe.

1. *Safety Valves.* Great care should be exercised to see that these valves are ample in size and in working order. Overloading or neglect frequently leads to the most disastrous results. Safety valves should be tried at least once every day to see that they will act freely.

2. *Pressure Gage.* The steam gage should stand at zero when the pressure is off, and it should show the same pressure as the safety valve when that is blowing off. If not, then one is wrong and the gage should be tested by one known to be correct.

3. *Water Level.* The first duty of an engineer before starting, or at the beginning of his watch, is to see that the water is at the proper height. Do not rely on glass gages, floats or water alarms, but try the gage cocks. If they do not agree with water gage, learn the cause and correct it.

4. *Gage Cocks and Water Gages* must be kept clean. Water gages should be blown out frequently, and the glasses and passages to gage kept clean. The Manchester (Eng.) Boiler Association attributes more accidents to inattention to water gages, than to all other causes put together.

5. *Feed Pump or Injector.* These should be kept in perfect order, and be of ample size, No make of pump can be expected to be continually reliable without regular and careful attention. It is always safe to have two means of feeding a boiler. Check valves and self-acting feed valves should be frequently examined and cleaned. Satisfy yourself frequently that the valve is acting when the feed pump is at work.

6. *Low Water.* In case of low water, immediately cover the fire with ashes (wet if possible) or any earth that may be at hand. If nothing else is handy use fresh coal. Draw fire as soon as it can be done without increasing the heat. Neither turn on the feed, start or stop engine, nor lift safety valves until fires are out, and the boiler cooled down.

7. *Blisters and Cracks.* These are liable to occur in the best plate iron. When the first indication appears there must be no delay in having it carefully examined and properly cared for.

8. *Fusible Plugs*, when used, must be examined when the boiler is cleaned and carefully scraped clean on both the water and fire sides, or they are liable not to act.

9. *Firing.* Fire evenly and regularly, a little at a time. Thin firing must be used where the draft is poor. Take care to keep grates evenly covered, and allow no air-holes in the fire. Do not clean fires oftener than necessary. With bituminous coal, a "coking fire," *i. e.*, firing in front and shoving back when coked, gives best results, if properly managed.

10. *Cleaning.* All heating surfaces must be kept clean outside and in, or there will be a serious waste of fuel. The frequency of cleaning will depend on the nature of fuel and water. As a rule, never allow over $\frac{1}{16}$-in. scale or soot to collect on surfaces between cleanings. Hand-holes should be frequently removed and surfaces examined, particularly in the case of a new boiler, until

proper intervals have been established by experience. In water tube boilers, for inspection remove the hand-holes at both ends of the tubes, and by holding a lamp at one end and looking in at the other, the condition of the surface can be fully seen. Push the scraper through the tube to remove sediment, or if the scale is hard, use the clipping scraper made for that purpose. Water through a hose will facilitate the operation. In replacing hand-hole caps, clean the surfaces without scratching or bruising, smear with oil and screw up tight. Examine mud-drum and remove the sediment.

The exterior of tubes can be kept clean by the use of blowing pipe and hose through openings provided for that purpose. In using smoky fuel, it is best to occasionally brush the surfaces when steam is off.

11. *Hot Feed-Water.* Cold water should never be fed into any boiler when it can be avoided, but when necessary it should be caused to mix with the heated water before coming in contact with any portion of the boiler.

12. *Foaming.* When foaming occurs in a boiler, checking the outflow of steam will usually stop it. If caused by dirty water, blowing down and pumping up will generally cure it. In cases of violent foaming check the draft and fires.

Water tube boilers should never foam with good water, unless the water is carried too high. If found to prime, lower the water line.

13. *Air Leaks.* Be sure that all openings for admission of air to boiler or flues, except through the fire, are carefully stopped. This is frequently an unsuspected cause of serious waste.

14. *Blowing Off.* If feed water is muddy, or salt, blow off a portion frequently, according to the condition of the water. Empty the boiler every week or two and fill up afresh. When surface blow-cocks are used, they should be often opened for a few minutes at a time. Make sure no water is escaping from the blow-off cock when it is supposed to be closed. Blow-off cocks and check valves should be examined every time the boiler is cleaned.

15. *Leaks.* When leaks are discovered they should be repaired as soon as possible.

16. *Emptying.* Never empty the boiler while the brickwork is hot.

17. *Filling Up.* Never pump cold water into a hot boiler. Many times leaks and, in shell boilers, serious weakness, and sometimes explosions are the result of such an action.

18. *Dampness.* Take care that no water comes in contact with the exterior of the boiler from any cause, as it tends to corrode and weaken the boiler. Beware of all dampness in seatings or coverings.

19. *Galvanic Action.* Examine frequently parts in contact with copper or brass, where water is present, for signs of corrosion. If water is salt or acid, some metallic zinc placed in the boiler will usually prevent corrosion, but it will need attention and renewal from time to time.

20. *Rapid Firing.* In boilers with thick plates or seams exposed to the fire, steam should be raised slowly, and rapid or intense firing avoided. With thin water tubes, however, and adequate water circulation, no damage can come from that cause.

21. *Standing Unused.* If a boiler is not required for some time, empty and dry it thoroughly. If this is impracticable, fill it quite full of water, and put in

a quantity of common washing soda. External parts exposed to dampness should receive a coating of linseed oil.

22. *General Cleanliness.* All things about the boiler room should be kept clean and in good order. Negligence tends to waste and decay.

BOILER WATER.

The character of water obtainable for steam making is too important a matter in station location and operation to be overlooked, both in regard to the corrosion of the boiler and to the scale forming a barrier between the heating surface and the water, reducing the efficiency of the boiler.

The following waters are available for boiler uses:

Rain water collected in the open country is usually nearly pure, but in the city it is objectionable because containing many impurities.

Surface water is usually well adapted for boiler use except that it is usually turbid. This turbidity can be removed by settling tanks or filters. It contains a small amount of dissolved solids and is low in carbonic acid.

Subsoil water obtained from springs and wells is clear, usually low in mechanically suspended matter but high in solids in solution. In periods of drought the soluble matter in subsoil water increases rapidly and water that will not give a troublesome scale ordinarily will cause trouble during a drought.

Artesian well or deep water varies greatly in its character, even in a given locality. It is apt to be rich in dissolved solids. Iron compounds and sodium chloride are often present in such considerable quantities as to make the water unsuitable for boiler use.

Waters of very high purity are liable to corrode the boiler badly, pure water having a corrosive action on the iron, either due to the carbonic acid or oxygen.

Waters taken from marshes and where brought in contact with masses of organic matter are liable to contain acids, which when introduced into the boiler corrode it, due to the presence of this organic matter in the water. This water may be neutral to iron at normal temperatures, but on raising the temperature of the water they may become active agents. Water of this character can be tested by heating with iron filings or clean suspended iron plates, and the precipitate can be noticed; but it is to be remembered that a boiler that has scale on it already does not present an active iron surface to this organic matter.

Corrosion in the boiler due to free acids may be overcome by neutralizing acids with an alkali such as caustic soda or soda ash. Corrosion due to the decomposition of magnesium salt can be benefited by almost any of the methods adaptable to prevent scale. Corrosion due to dissolved oxygen can be materially reduced by heating the feed-water before introducing into the boiler. The magnesium and calcium carbonates can be held in solution by carbonic acid precipitated when that acid is removed or neutralized. This may be accomplished by heating the water or exposing it in thin layers to the action of the air; or the neutralizing of carbonic acid may be brought about by the addition of slack-lime or calcium hydroxide, which converts the carbonic acid into an insoluble carbonate precipitating both itself and carbonates in solution.

The precipitation of calcium sulphate is more difficult. This is soluble in water to the extent of 100 grains to a gallon, and is much less soluble at boiling point. This precipitation can be accomplished by heat alone, but it must be under decided pressure. Calcium sulphate is the most objectionable ingredient, as it forms a hard scale. One remedy is to use organic matters in the boiler which act by interfering with the crystallization of the sulphate, and thus render the deposit in the boiler more easy to be removed. But the modern tendency is to use a direct precipitating agent for calcium sulphate, such as trisodium phosphate and sodium fluoride; these substances convert calcium and magnesium compounds into insoluble, flocculent precipitates, yielding also highly soluble and non-corrosive sodium salts.

Crude oil, kerosene, soda and tannic acid (many of the boiler compounds contain in greater or less quantities these chemicals) are used for removing scale from boilers or making a precipitate of a muddy character, so that it can be blown off by the regular cleaning of the boiler.

The engineer may make the following tests in order to determine roughly the character of water he has to deal with: Take a large, tall, clear glass vessel filled with the water to be tested; add to it, while stirring, a few drops of ammonia until the water is distinctly alkaline—this can be tested by litmus paper—next add a little phosphate of soda, the action of which is to change lime or magnesia into a phosphate which forms a deposit at the bottom of the glass. The water can then be filtered through a paper filter, leaving the precipitate in the filter, which can be weighed. This gives a relative idea of the quantity of sediment and scale-making material in the water.

Water, which will turn litmus paper red before boiling, contains acid; and, if the blue color can be restored by heating, the water contains carbonic acid.

If water has a foul odor and gives a black precipitate with acetate of lead it contains sulphur in various combinations.

The hardness of water can be determined in the following way; Dissolve castile soap in a glass of water and then stir into the water to be tested a few teaspoonfuls of this solution; the matter deposited will show the comparative amount of scale-making material contained in the feed water.

The following chemical tests will indicate the character of the impurities in the water, by causing a precipitate:

Carbonic acid is indicated by byrata water.
Sulphates are indicated by chloride of barium.
Chlorides are indicated by nitrate of silver.
Lime salts are indicated by oxalate of ammonia.
Organic matter is indicated by chloride of mercury.

Heaters and Purifiers.—As many of the impurities are removed by heating water, water heaters act as purifiers. Magnesium and carbonates are thrown down out of the heated water in the form of scale on the heater surface. In the open heater the water is spread out in open pans and the exhaust steam comes in direct contact with the agitated water; the shell as well as the pans is generally made of cast iron, as this is not as liable to corrosion as steel and rolled iron. There are a number of forms of this type of heater, involving the spraying of the water through which the exhaust or live steam is driven, and the water is allowed to settle in pans or troughs, where the precipitate of the impurities which will not stay in solution at these temperatures is thrown down. The heated water is held in a reservoir until taken from it by a pump into the boiler.

In the closed type of heaters, the cold water is conveyed through a nest of pipes, around the outside of which the exhaust steam circulates. In some cases the steam passes through the nest of pipes surrounded by the feed water to be heated.

The dimensions per horse-power for feed water heaters were rated as follows at a meeting of the feed water heater manufacturers:

It was decided that a heater should be rated in horse-power for each ⅛ sq. ft.

of tube heating surface in the heater. The horse-power of the boilers at normal load was taken as the size of the heater, but heaters larger than required give additional capacity to the boilers to stand sudden overloads.

One of the principal points of construction is, that sufficient flexibility be given the tubes so that leaks will not start, due to their expansion and contraction with changes in temperature. They should not be contracted in the steam areas so as to create a back pressure on the engine; this can be ascertained by taking cards on the engine, exhausting through the heater and then exhausted directly to air. The temperature to which a heater raises the feed water is with exhaust steam less than 212 degs., and the temperature should be taken while the heater is delivering its full supply of water to the boilers.

PERCENTAGE OF SAVING IN FUEL BY HEATING FEED-WATER. STEAM AT 70 LBS. GAGE PRESSURE.

Initial Temp. Feed	TEMPERATURE TO WHICH FEED IS HEATED.														
	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	250°	300°
35°	5.53	6.38	7.24	8.09	8.95	9.89	10.66	11.52	12.38	13.24	14.09	14.95	15.81	19.40	29.34
40°	5.12	5.97	6.84	7.69	8.56	9.42	10.28	11.14	12.00	12.87	13.73	14.59	15.45	18.89	28.78
45°	4.71	5.57	6.44	7.30	8.16	9.03	9.90	10.76	11.62	12.49	13.36	14.22	15.09	18.37	28 22
50°	4.30	5.16	6.03	6.89	7.76	8.64	9.51	10.38	11.24	12.11	12.98	13.85	14.72	17.87	27.67
55°	3.89	4.75	5.63	6.49	7.37	8.24	9.11	9.99	10.85	11.73	12.60	13.48	14.35	18.38	27.12
60°	3.47	4.34	5.21	6.08	6.96	7.84	8.72	9.60	10.47	11.34	12.22	13.10	13.98	16.86	26.56
65°	3.05	3.92	4.80	5.67	6.56	7.44	8.32	9.20	10.08	10.96	11.84	12.72	13.60	16.35	26.02
70°	2.62	3.50	4.38	5.26	6.15	7.03	7.92	8.80	9.68	10.57	11.45	12.34	13.22	15.84	25.47
75°	2.19	3.07	3.96	4.84	5.73	6.62	7.51	8.40	9.28	10.17	11.06	12.95	12.84	15.33	24.92
80°	1.76	2.65	3.54	4.42	5.32	6.21	7.11	8.00	8.88	9.78	10.67	11.57	12.46	14.82	24.37
85°	1.30	2.22	3.11	4.00	4.90	5.80	6.70	7.59	8.48	9.38	10.28	11.18	12.07	14.32	23.82
90°	0.89	1.78	2.68	3.58	4.48	5.38	6.28	7.18	8.07	8.98	9.88	10.78	11.68	13.81	23.27
95°	0.45	1.34	2.25	3.15	4.05	4.96	5.86	6.77	7.66	8.57	9.47	10.38	11.29	13.31	22.73
100°	0.00	0.90	1.81	2.71	3.62	4.53	5.44	6.35	7.25	8.16	9.07	9.98	10.88	12.80	22.18

The heater should be placed between the pump and the boiler, so cold water can be handled by the pump. Hot water gives trouble in a number of places by eating and wearing the working parts of the pumps, so that they leak and the heater in this case has to stand full boiler pressure.

Economizers —Here the flue gases pass around cast-iron pipes, containing the feed water, and the temperature of the water can be brought up to boiler water temperature. This form of heater removes the scale-making solvents from the water more effectively than heaters deriving their heat from steam. The construction usually employed consists of a battery of vertical cast-iron pipes connected with headers, which are large enough for both water circulation, and containing deposit from the water. The economizer is built into the flue, which is enlarged to accommodate it; a by-pass is also provided so the gases can be passed directly to the chimney, so that cleaning and repairing can be made without shutting down.

The use of economizers increases the actual steaming capacity of the boiler and tends to hold the steam pressures constant. With varying steam demands they can improve the efficiency of the boiler plant from 10 per cent to 18 per cent depending upon local conditions. Where placed in a plant already installed, they reduce the effectiveness of the chimney draft, and may from this cause decrease the available heating value of the coal burnt; but with artificial draft they can be operated with undoubted economy. The soot and ashes should be cleaned by automatic scrapers from the tubes about one hour in twenty-four, depending upon the character of smoke passing through the economizer.

The table herewith gives the results of tests on nine plants using mechanical drafts and economizers.

TESTS OF ECONOMIZER AND MECHANICAL DRAFT PLANTS, SHOWING INITIAL AND FINAL TEMPERATURES OF FLUE GASES AND FEED WATER IN DEGS. FAHR.

Plants Tested.	Gases Entering Economizer.	Gases Leaving Economizer.	Water Entering Economizer.	Water Leaving Economizer.	Gain in Temperature of Water.	Fuel Saving, Per cent.
1	610	340	110	287	177	16.7
2	505	212	84	276	192	17.1
3	550	205	185	305	120	11.7
4	522	320	155	300	145	13.8
5	505	320	190	300	110	10.7
6	465	250	180	295	115	11.2
7	490	290	165	280	115	11.0
8	495	190	155	320	165	15.5
9	595	299	130	311	181	16.8

Boiler Feeding Methods.—There are several methods employed for feeding boilers, one by directly forcing water into the boiler by city water pressure, where the pressure is high enough to overcome the boiler pressure; others by injectors or high-pressure pumps, either steam driven, belted or electric driven. The relative economy of the different methods of feeding boilers is given in the following table.

This relation does not show the true operating economy in pumps as usually employed in street railway work ; for here the pumps, where steam driven, are run at a slow speed much under their maximum capacity to make up for steam consumption in the boiler, and they take as high as 160 lbs. of steam per hp-hour, under this method of feeding; and makes the showing of belt and electric driven pumps 20 per cent to 36 per cent more efficient than steam driven pumps. With triple cylinder pumps, provided with by-passes so one or two cylinders can be thrown out of service to vary the water supply to the boilers, 35 per cent to 45 per cent greater efficiency is secured over the steam driven pump, doing the same duty.

The amount of water required by a battery of boilers is usually taken as 3.6 gals. of water per hp hour, or nearly ½ cu. ft. of water per hp-hour. Two independent methods are required to feed the boiler, the general arrangement is to use the injector and steam driven pumps. For boiler plants of over 600-hp capacity two pumps are generally installed, each capable of taking care of the whole battery. The pumps should be arranged, if possible, to take water from two sources of supply; it is advisable to arrange a storage capacity to carry the boiler for twenty-four hours in case of breakdown, where the city water system is depended on.

RELATIVE EFFICIENCY OF VARIOUS METHODS OF SUPPLYING FEED WATER TO BOILERS.

Temp. of feed water as delivered to the pump or to the injector, 60° F. Rate of evaporation of boiler, 10 lbs. of water per lb. of coal from and at 212 degs. F.	Relative amount of coal required per unit of time, the amount for a direct acting pump, feeding water at 60°, without a heater being taken as unity.	Saving of fuel over the amount required when the boiler is fed by a direct acting pump without heater.
Direct acting pump feeding water at 60 degs. without a heater	1.000	.0
Injector feeding water at 150 degs., without a heater.	.985	1.5 per cent
Injector feeding through a heater in which the water is heated from 150 to 200 degs	.938	6.2 " "
Direct acting pump feeding water through a heater in which it is heated from 60 to 200 degs	.879	12.1 " "
Geared pump run from the engine, feeding water through a heater, in which it is heated from 60 to 200 degs	.868	13.2 " "
Geared pump run from motor, rheostatic control	.838	16.2 " "
Geared pump, 3 cylinders with by-passes for regulation	.819	18.3 " "

FEED-WATER PUMPS AND INJECTORS.

The location of the pump where there is a natural head of water is one of convenience and shortest length of supply and delivery pipes, but where the pump has to take water from a well the suction pipe should be as short as possible. In horizontal runs of pipe the pipe should dip toward the supply end at least $\frac{1}{16}$ in. in a foot to prevent an air trap, which will affect the proper working of the pump, and the foot valve and strainer on the end of the suction pipe beneath the water should be so large that the accumulation of trash will not throttle the suction of the pump.

When the pump is required to handle hot water, the water must be delivered to the pump by gravity. Hot water pumps give more trouble than those for cold water, and their depreciation is as much as 40 per cent greater in handling ordinary boiler waters, while with waters containing sulphur, they are a continual source of annoyance. Cold water should be forced into the heating apparatus where possible.

Injectors.—The injector is capable of feeding water into a boiler, if the water is under 100 degs. in temperature. The injector consists of a tubular brass casting having three openings: the first one, *A*, in Fig. 174, is for the delivery of dry steam from the boiler; the second opening, *B*, is the inlet for the water to be fed; the third one, *I*, opening towards the boiler, is the one through which the feed water is to be forced by the steam. The injector operates upon the principle that a current of steam at high velocity will produce by suction a vacuum which draws the air from above the water in the supply pipe *B*; when the water rises it is forced through the nozzle *D;* the steam meeting the water from the supply pipe carries the water with it, on account of the energy of impact and condensation into the boiler lifting the check valve, *H*, to gain admission. The water is therefore injected into the boiler hot.

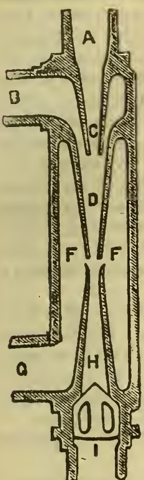


Fig. 174.
INJECTOR.

The injector is usually installed in railway plants as an alternative method for feeding the boilers where pumps or other methods are used; but its economy is so poor as a method of feeding the boilers that it is not used in regular service.

Injectors may be placed either in a horizontal or vertical position. They work best where the suction is not over 20 ft., and should be located as near the boiler as possible. It is the usual practice to supply an injector for each boiler or pair of boilers. Injectors work more effectively at low steam pressures than at high, but should be adjustable to work at varying steam pressures.

Steam Pumps.—A piston speed of 100 ft. per minute is the ordinary practice for a direct acting pump, but in a boiler feeding under heavy pressures, especially where hot water has to be pumped, a slower speed is advisable. The table herewith gives the sizes and capacity of pumps from 2 ins. to 12 ins.; this is the theoretical maximum amount that can be pumped, but on account of slippage and the leakage of the valves, the actual amount of water pumped will be less than that given in the table:

THEORETICAL CAPACITY OF STEAM PUMPS: SPEED OF PISTON OR PLUNGER 100 FT. PER MINUTE.

Diameter of Pump or Plunger in Inches.	Gallons discharged per Minute.	Diameter of Pump or Plunger in Inches.	Gallons discharged per Minute.
2	16.33	5	102.0
2¼	20.67	5¼	112.0
2½	25.52	5½	123.0
2¾	30.88	5¾	135.0
3	36.75	6	147
3¼	43.13	6½	172
3½	50.02	7	200
3¾	57.42	7½	229
4	65.34	8	261
4¼	73.76	8½	295
4½	82.7	9	330
4¾	92.14	9½	368
		10	408
		10½	450
		11	4[illegible]4
		12	587

In a duplex pump the number of gallons delivered per minute is found by multiplying the displacement of one plunger by twice the number of strokes.

The direct-acting steam pump is one in which the steam cylinder and water cylinder are centrally in line with each other so that the water plunger and steam piston are connected to the same piston rod. This form of pump gives the least first cost and occupies less space, but is perhaps the most wasteful and extravagant form, for the reason that the steam follows at full pressure throughout the stroke, getting none of the economies due to using the steam expansively. The duplex steam pump consists of two steam pumps of equal dimensions, placed side by side, and so arranged that the piston of each pump has a controlling movement of the slide valve of the opposite steam cylinder. This allows one piston to proceed to the end of the stroke and gradually come to a state of rest, while during the latter part of this movement, the opposite piston moves forward in its stroke and also gradually comes to a state of rest; but in moving forward and before reaching the end of the stroke, the slide valve controlling the first piston is reversed, and in consequence the first piston returns to its original position. These movements continue uniformly as long as steam is supplied to the pistons.

When the boiler pressure is from 65 lbs. to 100 lbs., a gain of from 20 to 35 per cent can be made over direct acting cylinders by compounding. But for pumps handling the amount of water necessary for railway plants of 1000 horse-power and under, the economy would not be of sufficient import to warrant the additional expense of a compound pumping apparatus, as the total amount of steam required for feeding the boilers is about $\frac{1}{27}$ of the output of the boiler.

The table on the opposite page gives sizes of suction and delivery pipe for piston speeds of 100 ft. per minute.

FRICTION OF WATER IN PIPES.

Friction loss in pounds per square inch for each 100 feet of different-sized clean iron pipe discharging a given quantity of water per minute.

Gallons per Minute.	Inside Diameter of Pipe.										
	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.	5 in.	6 in.	8 in.	10 in.	12 in.
20	4.07	1.66	.42	......	......	......	......	......	......	......	......
25	6.40	2.62	......	.21	.10	......	......	......	......	......	......
30	9.15	3.75	.91	......	......	......	......	......	......	......	......
35	12.4	5.05	......	......	......	......	......	......	......	......	......
40	16.1	6.52	1.60	......	......	......	......	......	......	......	......
45	20.2	8.15	.....	......	......	......	......	......	......	......	......
50	24.9	10.0	2.44	.81	.35	.09	0.03	......	......	......	......
75	56.1	22.4	5.32	1.80	.74	......	0.06	......	......	......	......
100	....	39.0	9.46	3.20	1.31	.33	0.10	.05	......	......	......
125	....	......	14.9	4.89	1.99	......	0.16	......	......	......	......
150	....	......	21.2	7.00	2.85	.69	0.23	.10	......	......	......
175	....	......	28.1	9.46	3.85	......	0.32	......	......	......	......
200	....	......	37.5	12.47	5.02	1.22	0.42	.17	......	......	......
250	....	......	......	19.66	7.76	1.89	0.65	.26	.07	.03	.01
300	....	......	......	28.06	11.2	2.66	0.94	.37	.09	.04	......
350	....	......	......	......	15.2	3.65	1.28	.50	.12	.05	.02
400	....	......	......	......	19.5	4.73	1.68	.65	.16	.06	......
450	....	......	......	......	25.0	6.01	2.10	.81	.20	.07	.03
500	....	......	......	......	30.8	7.43	2.70	.96	.25	.09	.04
750	....	......	......	......	......	......	5.40	2.21	.53	.18	.08

DIAMETERS SUITABLE FOR SUCTION AND DELIVERY PIPES FOR DUPLEX DIRECT-ACTING PUMPS: PISTON SPEED 100 FT. PER MINUTE.

Water-Cylinder.		Suction-Pipe.			Delivery-Pipe.		
Diameter.	Area.	Diameter.	Area.	Velocity of Flow at 100 Feet.	Diameter.	Area.	Velocity of Flow at 100 ft.
Inches.		Inches.		Feet.	Inches.		Feet.
4	12.57	3	7.07	178	2	3.14	400
5	19.64	4	12.57	156	3	7.07	277
6	28.27	5	19.64	143	4	12.57	224
7	38.48	6	28.27	136	5	19.64	196
8	50.27	6	28.27	180	5	19.64	256
9	63.62	8	50.27	126	6	28.27	225
10	78.54	8	50.27	156	7	38.48	204
12	113.09	10	78.54	144	8	50.27	224
14	153.93	12	113.09	136	10	78.54	196

THEORETICAL HORSE-POWER REQUIRED TO RAISE WATER TO DIFFERENT HEIGHTS.

Gallons per Minute	60 feet	75 feet	90 feet	100 feet	125 feet	150 feet	175 feet	200 feet	250 feet	300 feet	350 feet	400 feet
25	.37	.47	.56	.62	.78	.94	1.09	1.25	1.56	1.87	2.19	2.50
30	.45	.56	.67	.75	.94	1.12	1.31	1.50	1.87	2.25	2.62	3.00
35	.52	.66	.79	.87	1.08	1.31	1.53	1.75	2.19	2.62	3.06	3.50
40	.60	.75	.90	1.00	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00
45	.67	.84	1.01	1.12	1.41	1.69	1.97	2.25	2.81	3.37	3.94	4.50
50	.75	.94	1.12	1.25	1.56	1.87	2.19	2.50	3.12	3.75	4.37	5.00
60	.90	1.12	1.35	1.50	1.87	2.25	2.62	3.00	3.75	4.50	5.25	6.00
75	1.12	1.40	1,69	1.87	2.34	2.81	3.28	3.75	4.69	5.62	6.56	7.50
90	1.35	1.68	2.02	2.25	2.81	3.37	3.94	4.50	5.62	6.75	7.87	9.00
100	1.50	1.87	2.25	2.50	3.12	3.75	4.37	5.00	6.25	7.50	8.75	10.00
125	1.87	2.34	2.81	3.12	3.91	4.69	5.47	6.25	7.81	9.37	10.94	12.50
150	2.25	2.81	3.37	3.75	4.69	5.62	6.56	7.50	9.37	11.25	13.12	15.00
175	2.62	3.28	3.94	4.37	5.47	6.56	7.66	8.75	10.94	13.12	15.31	17.50
200	3.00	3.75	4.50	5.00	6.25	7.50	8.75	10.00	12.50	15.00	17.50	20.00
250	3.75	4.69	5.62	6.25	7.81	9.37	10.94	12.50	15.72	18.75	21.87	25.00
300	4.50	5.62	6.75	7.50	9.37	11.25	13.12	15.00	18.75	22.50	26.25	30.00
350	5.25	6.56	7.87	8.75	10.94	13.12	15.31	17.50	21.87	26.25	30.62	35.00
400	6.00	7.50	9.00	10.00	12.50	15.00	17.50	20.00	25.00	30.00	35.00	40.00
500	7.50	9.37	11.25	12.50	15.62	18.75	21.87	25.00	31.25	37.50	43.75	50.00

The preceding table gives the actual water-horse-power. When selecting motors or pumps, allowance must be made for pipe friction and loss in the pump, gears belts, etc. One foot head equals .43 pound pressure to the square inch.

Electrically Driven Pumps.—These are driven by being geared or belted to a motor, the speed of which is controlled by a regulating rheostat. The duplex or triplex pumps, with heavy flywheels, give the best service, and have the highest economy of all methods of boiler feeding.

CHIMNEYS AND DRAFT.

In order to produce the rate of combustion necessary in the grate of the boiler, air has to be forced or drawn through the fire at a greater speed than that caused by local differences of temperatures. The chimney may be used alone or forced or induced draft be employed.

One pound of coal requires from 12 lbs. to 16 lbs. of air for its combustion. Anthracites require the least and bituminous more in proportion to their volatile constituents. For the best results in combustion an excess of air, over that required chemically, is desirable, varying from 18 lbs. to 24 lbs. of air depending upon the character of coal.

The introduction of this surplus air reduces the possible heat units attainable from 6 per cent to 12 per cent of the heating value of every pound of coal, since this surplus air has to be drawn through the fire and heated from 60° to 500° Fahrenheit.

The draught in a chimney is produced by the difference in weight of the hot gases in the chimney and the cold air outside, and can be considered as an unbalanced inverted siphon with the heavy cold air on one leg attempting to restore the equilibrium by forcing air through the grate fires, flue and chimney. A draught is usually measured in inches of water, that is, with a U-tube partly filled with water, one end connected to the draught to be measured and the other end open; the difference of water level will give the draught pressure in inches. One inch difference in water level means 0.577 ounces per sq. in.

The chimney should be located so as to give the least length of flue from boiler to chimney, preferably in the middle of a battery of boilers. The foundations should be carefully proportioned and independent of any building foundations; and no connections of the breeching to the chimney should be made until the chimney is completely erected and settled down on its foundations.

Construction of Brick Chimneys.—The total weight of a brick chimney must be greater than the total wind pressure against it. Every square foot exposed of a square chimney should be designed to withstand a maximum wind pressure of 56 lbs. per sq. ft. A hexagonal chimney reduces this to 42 lbs.; an octagonal, 36 to 34 lbs. and a circular, 30.8 lbs. The circular is the best form for a chimney as it makes the best flue and is economical in material. Roughly the diameter at the base of a chimney should be $\frac{1}{10}$ of its height. The following table gives the height and sizes for chimneys for different horse-power of boilers, based on an assumed evaporation of 7 lbs. of water per pound of coal, or an equivalent evaporation of 5 lbs. of coal per hp-hour.

The ratio of the cross section of a chimney to the grate area is usually taken as 8 to 1. J. J. De Kinder found that 75 ft. was the best height for free burning bituminous coals, 115 for slow burning bituminous coals and 125 to 150 ft. for fine anthracite coals.

CHIMNEY DIMENSIONS WITH CORRESPONDING HORSE-POWERS.

Area Square Feet.	Diameter. Inches.	HEIGHTS IN FEET.												
		75	80	85	90	95	100	110	120	130	140	150	175	200
		COMMERCIAL HORSE POWER.												
3.14	24	75	78	81	....	....	....	......	......	......	......	....	....	....
3.69	26	90	92	95	98	....	....	......	......	......	......	....	....	....
4.28	28	....	106	110	114	117	1[illegible]	......	......	......	......	....	....	....
4.91	30	....	122	127	130	133	137	......	.....	......	......	....	....	....
5.59	32	....	....	144	149	152	156	164	......	......	......	....	....	.. .
6.31	34	....	....	162	168	171	176	185	......	......	......	....	....	....
7.07	36	....	....	....	188	192	198	208	215	......	......	....	....	....
8.73	40	....	....	....	....	237	244	257	267	279	......	....	....	....
10.56	44	....	....	....	....	287	296	310	322	337	......	...	....	....
12.57	48	....	....	....	....	....	352	370	384	400	413	....	....	....
15.90	54	....	....	....	....	....	445	468	484	507	526	....	....	....
19.63	60	....	....	...	....	....	....	577	600	627	650	672	....	....
23.76	66	....	....	....	....	....	....	697	725	758	784	815	....	....
28.27	72	....	....	....	....	....	....	......	862	902	932	969	1044	....
38.48	84	....	....	....	....	....	....	......	1173	1229	1270	1319	1422	....
50.27	96	....	....	....	....	....	....	......	......	1584	1660	1725	1859	1983
63.62	108	....	....	....	....	....	....	......	......	2058	2102	2181	2352	2511
78.54	120	....	....	....	....	....	....	......	......	......	2596	2693	2904	3100

Allowance must be made where flues are longer than 50 ft., and height added to the chimney to make up for the loss in heat of the draft and friction. The table following gives the loss in effectiveness of chimney draught in per cent, which is due to long flues.

REDUCTION OF CHIMNEY DRAFT BY LONG FLUES.

Total length of flues in feet..	50	100	200	400	600	800	1000	2000
Chimney draught in per cent	100	93	79	66	58	52	48	35

Local conditions, such as adjacent hills, atmosphere ladened with moisture, elevation above the sea level, etc., reduce the theoretical draught; and ample allowances should be made so that the chimney will be able to completely burn the combustible under the worst conditions, both of coal and weather, It is well to bear in mind that without proper draft all other boiler economies are futile.

Iron Stacks.—These are formed of plate iron, lap or butt riveted, and made up in sections of convenient size. They may be made self-supporting with a flaring base, or may be guyed two-thirds of the way up with four or more guy rods or chains. They are usually lined with fire brick part of the way up.

Breeching and Flues.—The connecting flues between the boiler and chimney are preferably round, as that form presents the easiest passage for the gases at the lowest first cost. All bends should be made with an easy curve. All joints should be riveted and sealed with luting, means being provided for cleaning. Where two flues enter the main flue opposite each other, there should be a baffle plate interposed in the main flue between the openings to prevent back drafts. The covering of flues with insulating covering that will resist the temperature will increase the effectiveness of the chimney.

Dampers.—Pivoted gates are introduced into the flue so the draft can be controlled, depending upon the steam required from the boiler, and the main damper can be regulated automatically by the steam pressure, so that when the pressure falls the dampers open to produce greater draft.

Mechanical Draft.—As the chimney is limited in capacity by its dimensions and weather conditions, mechanical methods of producing the flow of air through the furnace have been adopted in a number of railway plants, with economy in first cost over an equivalent chimney, and giving greater and more readily controlled draft. By this means the boiler can respond readily to additional demands, and the rate of combustion on the grate can be carried beyond that possible to be obtained from natural draft only.

Induced Draft.—A steam jet may blow up the stack, inducing a draft. This method, while being the most economical in installation, consumes from 8 to 20 per cent of the steam made by the boiler to produce the required draft. The steam introduced into the hot gases reduces their volume and effectiveness, and such an arrangement is so noisy that very few power stations are so located as to be able to use it.

In mechanically induced draft systems a fan is introduced between the boilers and the stack, which draws the air through the fire and boiler, and ejects it from the chimney. The fan can be operated by an electric motor or an engine, whose speed can be controlled in order to vary the rate of combustion in the furnace to meet the required steam demand. By having a controllable air supply, complete combustion and consequently greater evaporative results from the coal can be obtained at a cost of 1 per cent to 4 per cent of steam from the boiler.

Forced Draft or Plenum Method.—This may be accomplished in two ways: first, by making the ash pit practically air-tight, and forcing into it sufficient air for combustion; or second, a method only practicable in steamships, by making the fire room air-tight, maintaining sufficient air pressure in this room to produce the required draft. The first method, which is applicable to street railway boiler rooms, does not give the results in practice of the induced draft, and subjects the fireman, where hand firing is done, to considerable heat on opening the fire doors. The test carried out on the steamer, H. M. S. Polyphemus, gives comparative results between the forced and induced method as follows:

RESULTS OF EXPERIMENTS AT PORTSMOUTH DOCK YARD WITH BOILERS OF H. M. S. POLYPHEMUS.

Kind of Draft.	Duration. Hours.	Average Steam Pressure. Pounds.	Temperature.		Total Coal Consumed. Pounds.	Total Water Evaporated. Pounds.	Lbs Water Evaporated per lb. Coal.		Lbs. of Coal Consumed per Hr. per Sq. Ft. of Grate.	Lbs. Water Evaporated per hour per Sq. Ft. Grate.		Approximate I. H. P.
			Feed.	Atmosphere.			At Actual Temp.	At 212°		At Actual Temp.	At 212°	
Induced	96	74.2	62°	69.9°	80,600	777,044	9.64	11.13	40.4	389.6	450.4	426.
Forced	96	77.3	51°	49.8°	94,500	759,338	8.03	9.3	47.3	381	444.	395.

THE STEAM ENGINE.

The steam engine, to successfully maintain potential on a street railway system at maximum economy, must possess features which fit it particularly for that work. Increasing the number of car equipments averages out the characteristics of the individual equipment, as the character of service changes with the number of equipments. The engine will be considered with regard to its economical performance, regulation and maintenance in connection with the following demands: 20-car road, 35-car road, 60-car road, 150-car road, and 300-car road and over.

With 20 cars the variations are large and rapid, and an engine, which will not respond readily to an increased load, drops the potential on the system, and retards the acceleration or speed of all cars operating, thus decreasing the possible external efficiency. It will be seen that the slower the initial speed of the engine, the larger the volume of steam that is taken at each stroke in order to give the same horse-power. In the Corliss type of engine for small roads, the load can vary much more rapidly than the governor can control the steam, and this rapid variation throws strains throughout the engine in the interchange of power between the flywheel and piston. The greater the inertia of the flywheel, the longer will be the period required for the governor to respond to the changing demands.

The first cost of a slow-speed engine, where direct-connected to the generator, is higher than that of an equivalent high-speed engine. The economy of the Corliss type of engine has often been judged for railway work from its full load efficiency, whereas carrying efficiently loads of one-half to three-quarters full load is required for this class of power station service. Consequently the adaptability of engines to the different character of loads found in the various railway stations must be carefully considered, in order to determine what class of engine will give the best average economy.

In determining this for a new road where the equipment is fixed, the constants for the equipment should be determined for grades, speeds and loads. Where mixed equipments are used, the data should be based on the largest equipment where the traffic ever requires their use over the entire system. In determining the current and potential required and the size of the unit for a new railway, the following points have to be borne in mind: The operation of the equipment under large line drops requires a greater current delivery, as its speed falls off on account of loss in potential on the line; allowance must be made in the size of the operating unit to make good all these losses without exceeding the allowable overload on the unit. Hence in collecting data for the purpose of accurately proportioning the engine and generator to the load, the current required by the equipment under maximum and mean transmission losses should be determined.

The greater the number of cars, the nearer the average load becomes a constant load, varying only with the number of cars in operation. Approximate results can be determined by referring to the curves in Fig. 175, which have been based on tests of roads operating equipments of two Westinghouse 12-A motors, with a 28 ft. car body and K-10 controller, the total equipment weighing 22,000 lbs.

Effect of Grades on Engine Loads.—The physical conditions of the road are reflected immediately on the engine demands. Curves given herewith, Fig. 175, show the relation of the maximum and mean demands on the engine for roads of from one car to fifty, and for three characters of roads, one possessing heavy grades, one moderate grades and one on level road.

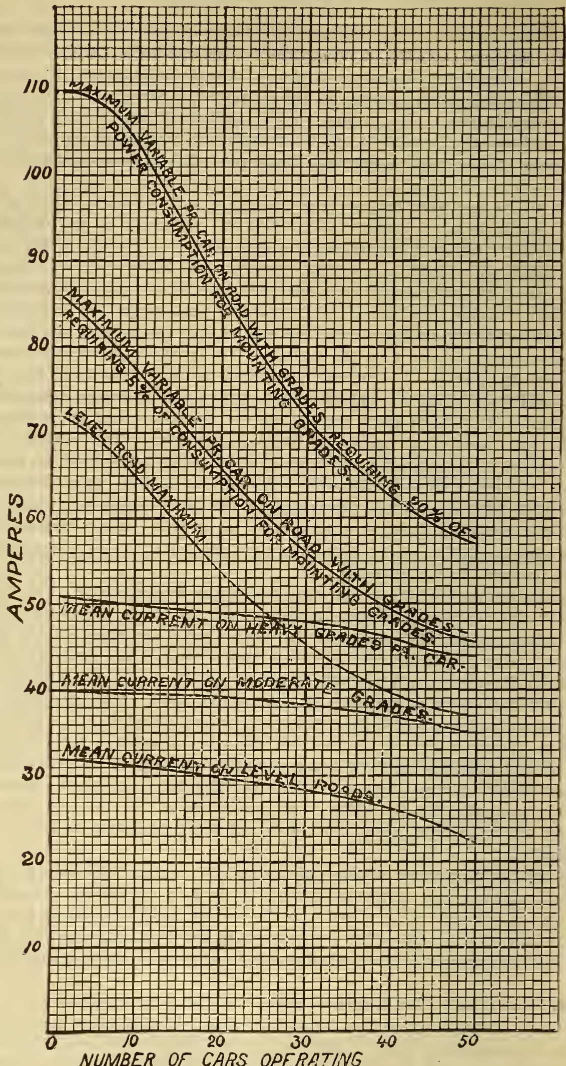


FIG. 175.—CURRENT PER CAR UNDER DIFFERENT CONDITIONS.

The effect of moderate grades below 3 per cent is to increase the starting current on the equipment, but the effect of the stored energy in the equipment in climbing such a grade is not fully recovered on the drifting of the equipment returning on this grade. The effect of a grade, averaging approximately between 3 per cent and 4½ per cent, will reduce the ratio between average and maximum current demands but increases the maximum demands, due to starting and carrying the equipment up the grade. In grades above 4½ per cent the maximum and average demands per equipment are both increased.

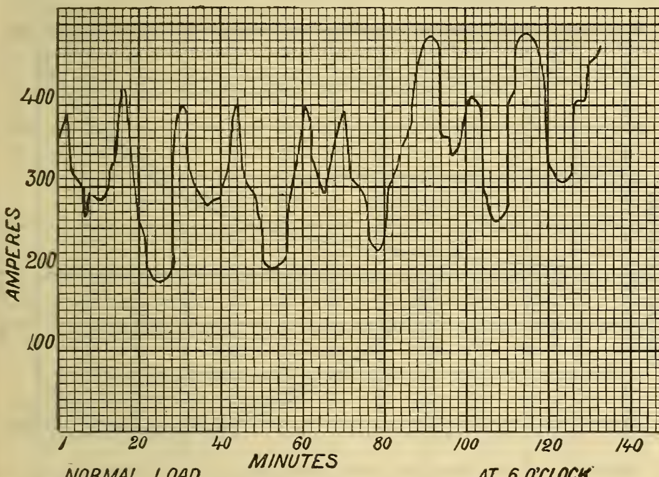


FIG. 176.—CURVE SHOWING VARIATION OF DEMAND ON STATION.

In order to determine the effect of the grade on the required output of the power station, the profile of the road is required, from which is determined the time from the schedule when the equipments require their maximum demand on the power station. It is very important in improvements in a power station for roads with 20 cars and under, or in a new station of the same capacity to have the average daily schedule carried by one engine, and to have this engine rated at maximum efficiency at about five-eighths to three-quarters of its maximum load. For roads in operation, the proper unit for maximum efficiency can be determined by the main ammeter readings. For fixed schedule on a 20-car road and under there will be found on taking minute readings, a cycle of changes which are periodic in character, depending upon the profile of the road and the coincidence of equipments requiring the maximum demand at the same time. This is especially marked in a single track road with turnouts.

Maximum Engine Efficiency.—Supposing a report from several daily observations, taken under different track and weather conditions, or estimated from the profile of the road and known equipment demands, showed a variation like that in Fig. 176, it is easy to see that here the maximum load obtained is 420 hp, the mean average load is 295 hp. For one unit to carry this service continually, the point of maximum efficiency of the engine should be 300 hp, and the maximum capacity of the engine 530 hp, including an overload possibility of 25 per cent, and the circuit-breaker set for this number of amperes. The additional load, caused by passengers at 7 a. m. and 6 p. m. and for days of special demand, will be much more profitably carried by an auxiliary unit than to operate two engines for the whole day, increasing the depreciation of the plant while neither engine would be using steam economically in the cylinder, and the friction losses would be doubled.

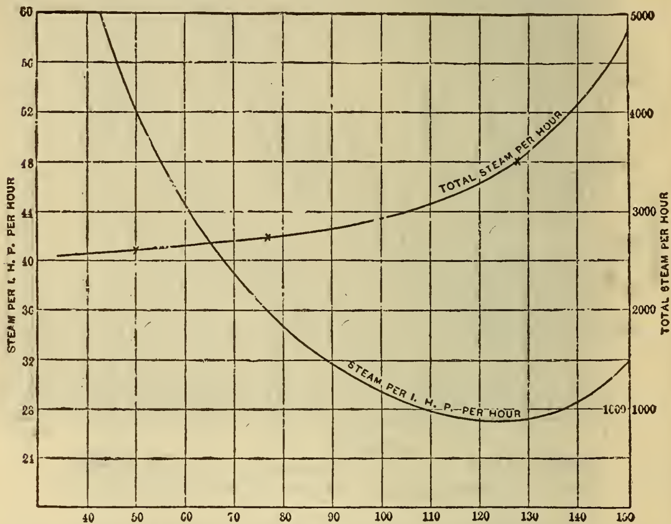


FIG. 177.—STEAM CONSUMPTION FOR DIFFERENT LOADS ON ENGINE.

In one test made by the author on a 32-car road, operating two Corliss engines, the operation required 62.3 lbs. of steam per kw-hour and both engines had a mean load of ⅝ full load; with one engine carrying the whole load, the steam consumption fell to 42 lbs. per kw-hour. The commercial value of this change to a single engine effected a saving in coal and oil sufficient to pay for all the power station labor.

Varying of Efficiency with Load.—When the load on an engine is reduced much below the rating, the friction per cent increases and also the cylinder condensation. The aggregate losses are shown in Fig. 177, as given by Prof. R. C. Carpenter, on a single non-condensing engine, 14 ins. x 16 ins., 120 lbs. steam pressure, 210 revolutions per minute.

While, in the 20-car to 30-car road, the number of equipments averages out the rapid maximums, the speed of the engine should still be moderate. With from 35 to 60 cars the question of the type of engine is varied by the characteristics of the road, as both high speed and moderate speed engines have shown about the same gross economy. The gross economy includes the cost of production, as well as fixed charges against the power station property; this is treated as a factory selling its product (current) at a cost which will cover every expense of operation, maintenance, depreciation, interest, taxes and insurance, and that proportion of executive expenses that the cost of the station bears to the whole property cost. With more than 60 cars the conditions of load become one where the engines can be worked at a slightly varying load from 80 per cent to 60 per cent of full load; and with their maximum efficiency between these points. Every means taken to increase the economy of the plant should be reflected in the operating costs per kw output in power plants of this size.

Records of the performances of different types of engines under railway loads have been obtained from the average of fifty-six tests taken on the basis of a four-hour and twenty-hour run, which are the average periods of service for all day operation and overload periods, and are tabulated below.

NON-CONDENSING ENGINES.	Lbs. of Coal per Indicated HP-Hour.	Tons (2,000 lbs.) per HP per year.	
		Day, 20 hrs.	Day, 4 hrs.
Simple, High Speed, Slide Valve, average..	4.71	17.19	3.44
" " " " " best	4.52	16.49	3.30
Simple Corliss, average....................	3.46	12.62	2.52
" " best........................	3.00	10.95	2.19
Compound Slide Valve, average............	4.09	14.92	2.98
" " " best................	3.91	14.27	2.85
CONDENSING ENGINES.			
Compound Slide Valve, average............	3.18	11.60	2.32
" " " best	2.22	8.10	1.62
Compound Corliss, average................	2.41	8.79	1.76
" " best	1.80	6.57	1.31

The tests on the engines show the value of the condensing type to a plant, but in the comparison between the Corliss and compound-condensing engine the loads on the Corliss tested were more favorable to economy than the loads on the compound-condensing moderate-speed engine; and, if the question of interest on first cost, oil and attendance were included in the aggregate expense of operation, the outcome will be in favor of the compound-condensing moderate-speed engine.

The tandem-compound, from the results of observation, gives the best results in stations under the 35-equipment class, both condensing and non-condensing, and the cross-compound for stations of the larger classes show good economy under operating conditions.

The elements of the economy of the Corliss valve gear have been introduced in moderate speed engines, giving this type of engine an additional economic value in railway work. One station has shown under mixed load 300 watt-hours output per lb. of coal under constant operation, using this type of engine.

The general classification of engines in regard to use of steam in cylinders is based on the number of expansions through which the steam passes in the engine. In the simple engine there is only one expansion; this may be of the high-speed or low-speed Corliss type. The compound engine uses steam expansively through two cylinders, which may be arranged in tandem, or the engine may be cross-compound, having one high and one low pressure cylinder on separate cranks 90 degs. apart, or the three cylinder compound engine where the first expansion takes place in the high pressure cylinder and the second expansions in two low pressure cylinders. The double tandem compound engine consists of two tandem compound engines, coupled to the same shaft 90 degs. apart.

The cost of an engine for any given power increases with the number of cylinders and expansion stages, but the economy of engines, with approximately constant load, increases with the number of expansions, providing the steam pressure is raised for the proper economy of steam through these expansions. So, in estimating the most profitable engine to procure for a given condition, the following values have to be balanced against each other; the interest on first cost, depreciation, cost of oil and attendance. The engine should be so selected that, with the road under consideration, it would bring the lowest interest charges on the cost of the boiler plant, and the least cost on coal and water consumption, the coal being the largest item, bearing about one-third to two-thirds of the total cost of power production. Only with very cheap coal and water and variable duty, will the simple high-speed engine show an economy of operation.

Division of Units.—The power station requires a duplicate set of engines, and in 20-car roads and under the stand by investment is large. The advisable division is usually as follows, the sizes of engines being selected to fit the generators as manufactured for railway work:

200	Horse-power	Maximum		................2- 200
300	"	"	"	................2- 300
400	"	"	"	................3- 200
500	"	"	"	................3- 250 or 4-175
600	"	"	"	................3- 300
800	"	"	"	................3- 400 or 4-300
1000	"	"	"	................3- 500 " 4-350
1200	"	"	"	................3- 600 " 4-400 or 5-300
1500	"	"	"	................3- 750 " 4-500
2000	"	"	"	................3-1000 " 4-750

In a road requiring more than 2000 horse-power, the division is limited by the size of the units which the market supplies; by combining, however, several sizes of units the greater factor of overload can be purchased for the least cost. There are several advantages in having a system of power units all of the same type, as they operate together and the engineer can experiment on them to determine how to get the best results in operation, but in long roads with few cars a small unit can often be used during the end and beginning of the schedule of each day, with a saving that will warrant the expenditure for this smaller unit.

Mechanical Strains.—The mechanical construction of an engine must give ample strength to the parts in order to withstand straining on overloads, and when the circuit-breaker opens. Engines built for factory service, especially of the slow-speed type, do not require the strength of parts of the railway engine, and to use that type of engine for railway work has led to a high rate of depreciation thereof. All parts subject to reciprocating strains have to be strengthened, and the engine is classed under the heavy duty type. Where a great section of metal is put in the frame of the engine, the piston-rod, connecting-rod, shaft and crank bearings are increased in size, and the flywheels should be constructed on different principles from those employed for factory loads.

Rotary and Piston Speeds.—The table on page 208 gives the revolution per minute and piston speeds of a number of types of engine, direct-connected to generators for railway and lighting work.

The following table gives the average approved revolutions per minute for railway engines:

500 kw	135 r. p. m.
1000 kw	100 r. p. m.
2000 kw and up	75 to 70 r. p. m.

DIMENSION OF ENGINE PARTS.

Clearances allowable with high-speed engines, with valves providing relief for entrained water vary with the size of the engine. The clearance volume bears no fixed relation to the total steam volume in the different engines for railway work, varying from $\frac{1}{8}$ ins. to $\frac{3}{8}$ ins. in the different sizes and types of engines. The clearance on the crank end is greater to take up the wear on every working joint between the piston and crank-pin; this allowance is generally $\frac{1}{16}$ in. for each joint. There are several methods for cutting down clearances, which have to be filled with steam at every stroke without doing useful work. One is to have the valves raised off their seats to allow relief for entrained water. Engines of this type have operated with 3 per cent clearance without trouble. Another method is to introduce pop valves, opening into the clearance spaces to relieve the entrained water. Still another method is a diaphragm placed so that it will be broken open when the pressure reaches 100 per cent over the maximum steam pressure.

Cylinder Walls.—In railway engines the bursting stress on the cast-iron cylinder walls should not exceed 2500 lbs.

Cylinder Heads.—The thickness of the cylinder heads vary with the diameter of the piston. 10 ins. diameter averages on a basis of 100 lbs. unbalanced pressure .68 ins.; 30 ins. diameter, 1.48 in.; 50 ins. diameter, 2.30 ins. An old rule is to make the cylinder head $1\frac{1}{4}$ times the thickness of the walls. Webbed heads should give equivalent strengths.

Cylinder Head Bolts.—No bolt smaller than $\frac{3}{4}$ in. should be used in cylinder heads. They should be spaced at a distance of about four or five times the thickness of the flange, and the strain on them should not exceed 5,000 lbs. per sq. in. for steel and 4,500 lbs. for wrought iron. The nut should engage threads to a greater depth than the diameter of the bolt under thread.

Piston Head.—The general rule is that the thickness of the piston head is equal to $\sqrt{\text{length of stroke} \times \text{the diameter of the piston}}$. Piston packings should be made approximately 1 per cent larger than the diameter of the cylinder and sprung into place. A section of ring is usually $\frac{1}{30}$ of the diameter of the cylinder plus $\frac{1}{8}$, and for width $\frac{1}{8}$ in. is added to the thickness.

The fit of the piston rod into piston is usually made by a combination of a straight and taper surface, the taper being about 3 ins. to a foot, which is drawn up to a shoulder by a nut. The strain on the bottom of this nut should not exceed 7,000 lbs. per sq. inch for steel and 5,500 for wrought iron.

Diameter of Piston Rods.—The average diameters of piston rods for railway engines should be at least $\frac{\text{diameter of cylinder}}{65} \times \sqrt{\text{Maximum working pressure} + 15}$.

Piston Rod Guides.—The pressure on the lubricating surfaces of piston rod guides should not exceed 350 lbs. Thurston gives the following value: The product of the relative velocity of the two surfaces in feet per minute of the guide multiplied by the maximum intensity of pressure should not be greater than 60,000.

Connecting Rod.—The ratio of the connecting rod length to stroke varies from 2:1 to 2½:1. Some of the more modern engines for railway work show slightly less than a 2 to 1 ratio, but this increases rapidly the wear on cross-head guides and friction surfaces; and with small clearances railway experiences certainly dictate longer connecting rods, even at a sacrifice of floor space in horizontal, and head room in vertical engines.

Crank Pin.—The pressure on a crank pin should not exceed 500 lbs. per sq. in. projected area or its length of bearing surface by diameter of pin. The crank pin is preferably made part of the crank arm or disc. In station engines the crank pin should be an integral part of the crank arm.

Engine Shaft.—With direct-connected units special conditions arise which throw strains on this shaft not encountered in belt driving. As an armature gradually falls out of alignment, due to the wear on the main shaft, the magnetic field is disturbed and an unbalanced pull occurs due to the smaller clearance on the lower part of the armature; this for an ⅛ in. difference in a 200-kw machine throws an additional pressure on the bearings of 21,400 lbs. approximately. Often when the bearings commence to heat in a direct-driven unit that has previously run smoothly, this is the place to look for the trouble. This can be found electrically by taking off the brush connecting cables with brushes down and fields excited

SIZE OF STEEL SHAFTS FOR DIRECT-CONNECTED UNITS.

Kw Output 575 Volts.	Rev.	Size of Shaft. Inches.	Rev.	Size of Shaft. Inches.	Rev.	Size of Shaft. Inches.
100	275	5½				
150	200	9				
200	200	10½	150	11½		
300	150	14	120	15	100	16
400	150	16	120	18	100	18
500	120	18	100	18	90	18
650	90	20				
800	120	22	100	22	80	22
1000	80	25				
1200	80	27				
1600	75	27				
2000	75	30				
2400	75	30				

and the generator running; if the field is distorted, due to unbalanced magnetic circuit, and the field winding is in good condition, a voltmeter will show higher voltage between those brushes bridging pole pieces which are too close to the armature. Boxes for shafts of direct-connected units should all be adjustable so that the generator can be re-aligned to make up for wear thereon. The proportions of the shaft depend on whether the generator is overhung or provided with outboard bearings; both methods of connection have been used and given satisfaction on railway loads. The overhung armature requires less floor space than that with outboard bearing. With a belted engine the outboard bearing is usually used. There is a tendency for a shaft beyond the engine to be deflected on account of the pressure on the crank pin. The sizes of steel shafts given on page 206 are advised for generators of 575 volts.

Engine Bearings.—Engine practice shows weight of bearings for direct-driven units as high as 460 lbs. per sq. in. of effective bearing surface; the belt-driving engine, 151 to 375 lbs. per sq. in. The length of the bearings on overhung armatures is 2¼ times the shaft diameter and 1½ times the shaft diameter with outboard bearing. Automatic, forced oil circulation has a great value in carrying away the heat from these friction surfaces; some engine makers introduce pipes into the pillow block casting through which water can be circulated in order to reduce the temperature. The character of shaft metal and the boxes in which they run should produce a glass surface and one on which the lubricant can reduce the friction coefficient to the lowest point.

Fly Wheels.—Armatures do not give sufficient centrifugal force to steady the engine and the drag of the armature through the field tends to make it behave as a brake wheel. An additional flywheel is necessary. While there is no case known of the bursting of a solid flywheel run on a high-speed engine, those on slow-speed engines have been wrecked, due to several causes. Where governor balls have been used for regulation in railway loads, the collar is continually working up and down over a narrow band with the result that at some time, if this point is not given particular attention, the governor will stick when the load goes off, and the engine will commence to race, or the safety stop may be out of order. A slack governor belt will let the engine run ahead of its rated speed. On examinations of flywheel explosions, where proper care has been taken of the engine, the failure has been due to two causes: one, the structural weakness of the flywheel and the other its location. The structural weakness occurs where a rim speed of 5000 ft. per minute and under and no greater strain on the rim section than 6000 lbs. per sq. inch is allowed. In the segmental form of casting, used where the spokes are cast directly to the rim, the fractures found on investigation show a very coarse grain at the fracture between the spoke and the rim. This would be due to shrinkages taking place between the rim and spoke, producing a character of metal here which has less than the calculated tensile strength. Built-up wheels should have the spoke and rim of separate castings, if possible for slow rotative speeds, or the rim may be built up of sheet iron; wire-wound flywheels have been used with success.

The wheel pit has often been made with small clearances between the wheel and the masonry of the foundation, and in two cases the driven pulley fractured first, the parts were drawn into the wheel pit and jammed under the flywheel and the engine wrecked.

The maximum diameter of flywheels of cast-iron allowable for railway work should not exceed the following figures for 5000 ft. peripheral velocity;

80 Rev. per minute	......83.25 ft. in circumference	.....26.5 ft. in diameter.
100 " "	......55.5 " "	.....17.7 " "
150 " "	......41.67 " "	.....13.3 " "
200 " "	......31.25 " "	..... 9.9 " "
250 " "	......22.73 " "	..... 7.2 " "

SOME DATA OF PROMINENT ENGINES.

	Cylinder Dimensions.	R. P. M.	Piston Speed Ft. per Minute.	Rated hp.	Max. hp.	Kw.	Type.
Glasgow, Scotland	11″ + 22″ x 24′	200	800	....	....	200	Hor., Tandem Comp., Cond.
Stockton, England	16″ + 32″ x 36″	94	564	400	....	300	Hor., Cross Comp., Cond.
Edison E. I. Co., Paterson, N. J	17″ + 36″ x 24″	150	600	600 625	Max. of without vacuum	400	Vert., Cross Comp., Cond.
Lorain & Cleveland R. Co., Cleveland, O.	20″ + 36″ x 48″	80	640	....	....	400	Hor., Cross Comp., Cond.
Toledo-Norwark R., Ohio	21½″ + 37″ x 22″	214	795	1000	....	500	Vert., Cross Comp., Cond.
United E. L. & P. Co., N. Y	21½″ + 37″ x 32″	200	733	1200	....	600	Vert., Tandem Comp., Cond. with low pres. cyl. on top.
Edison E. I. Co., Chicago, Ill	20″-30½″-50″ x 36″	120	720	....	....	800	Vert., Triple, Cond.
South Side Elevated, Chicago, Ill	26″ + 54″ x 48″	80	640	1200	2000	800	Hor., Cross Comp., Cond.
Metropolitan Supply Co., London, Eng.	36″ + 55″ x 36″	133	800	2500	3500	1500	Vert., Cross Comp., Non-Cond.
Edison E. I. Co., N. Y	26″-37″-52″-72″ x 36″	90	585	2500	2800	1600	Vert., Double Tan. Quad. Non-Cond.
Edison E. I. Co., Brooklyn, N. Y	2-24″ + 48″ x 66″	75	828	3000	5000	2000	Hor., Double Tan. Comp., Cond.
Third Ave. R., New York	46″-86″ x 60″	75	750	4500	7000	....	Vert., Cross Comp,, Cond.
Metropolitan R., New York	46″-86″ x 60″	75	750	4500	7000	3500	Vert., Cross Comp., Cond.

ENGINE TESTING.

Friction Losses.—Friction tests can be made on an engine, direct or belt-connected to the generator, as follows:

To test the bearing friction disconnect the connecting-rod from the crank-pin and secure it out of the way of the rotating crank. With a belted generator, the generator can be forced back on the belt-tightener guides and the belt supported away from the pulley. If there is a spare unit, this generator can be started up by connecting in parallel with the spare unit, when it is standing still; then start up the spare unit, and the generator will follow as a motor in speed with it.

The current and volts required to run this generator free as a motor at full speed can be determined; then the motor can be belted up to the fly-wheel of the engine and readings again taken, when the full speed of the flywheel has been reached. The difference in watts between the two readings will be the additional friction on the motor bearings due to belt tension, the belt losses and the friction of engine bearings.

The next test will require the valve chest being opened and the valves lifted from their seat, and the connecting-rod re-connected; then the watts required to run the engine at full speed this way will include all engine frictions except valve friction; subtracting the motor losses from the watts obtained will give the gross engine and transmission friction.

With a direct-connected generator the manufacturers usually can supply the figures for the current required to run the generator free, and this subtracted from the watts read in the above tests will give the bearing and engine frictions.

Prof. Thurston gives the following division of friction in a straight line engine, 6 ins. × 12 ins. balanced valve, No. 1, and 6 ins. × 12 ins. unbalanced valve, No. 2.

	1	2
Main bearings	47.0	35.4
Piston and rod	32.9	25.0
Crank-pin	6.8	5.1
Cross-head and Wrist-pin	5.4	4.1
Valve and rod	2.5	26.4
Eccentric strap	5.4	4.0
Total	100.0	100.0

In a compound condensing test, from 1 to 102.6 hp. gave friction horse-power varying from 14.92 to 17.42. The friction of belt-driven engines increases faster than direct-driven engines due to the belt tension reacting on engine bearings, but it is usual to call the friction load constant. In some slow-speed engines the friction has been found to fall slightly with increasing loads and this may also be noticed in some direct-driven compound generators, in which the field pull tends to raise the armatures from the engine bearings.

Engine Indicators.—The indicator is an apparatus for graphically recording the action of steam in the cylinder of the engine. Its operation is as follows: Cylinder *A*, Fig. 178, on which can be secured the paper for the record is so connected to the reciprocating parts of the engine, that it follows exactly the movement of the piston in the cylinder to and fro. A pencil, or stylus, *C*, is arranged on the end of a lever, which is actuated in a straight line by the pressure of the steam in the cylinder of the engine. The movement of this piston is controlled by a calibrated spring, *B*, which moves the stylus, *C*, in proportion to the steam pressure of piston, *D*. The steam is admitted to the bottom of piston *D* through the inlet, *E*, which is connected to the steam pipes from the ends of the engine cylinder. These two pipes meet in a three way cock, which can introduce steam from either end of the cylinder to the bottom of indicator piston, or can close both steam entrances and open the bottom of the indicator cylinder to atmosphere. The piping should not be smaller than ⅝ ins. in order that there be no throttling between the indicator and the steam in the engine cylinder.

Analysis of the Indicator Card.—At *A*, Fig. 179, will be found in a dotted line a loop projecting above the steam line; this indicates that the exhaust valve closes too soon, and the steam, entrapped in the cylinder on compression into the clearance spaces, exceeds the initial pressure. At *B* is indicated a clean cut-off.

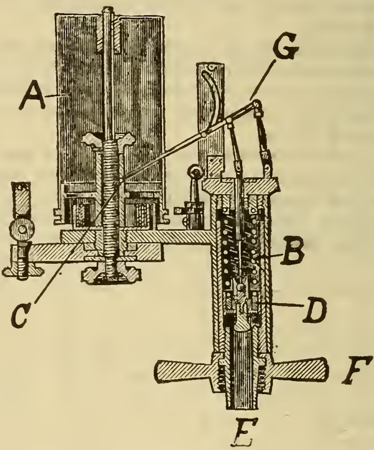


FIG. 178.—SECTION OF INDICATOR.

F will be a compromise for high speed simple engines, while *C* probably shows too small steam pipe connection between engine and boiler. A wavy line like *D*, will indicate two things: either an imperfect valve or friction in the indicator interfering with its correct action.

From the indicator card the mean effective pressure exerted on the piston as it sweeps through the cylinder can be computed.

In Fig. 180, the atmospheric line *A B* is a line drawn by the pencil of the indicator when the connection with the engine is closed, and both sides of the indicator piston are opened to the atmosphere. The clearance line *C A* is a reference line, whose distance from the end of the diagram *A K* bears the same ratio to *K B* as the clearance and waste-room volume bears to the total volume which is swept through by the piston. *C D* is the line of boiler pressure drawn parallel to the atmospheric line *A B* at the same pressure scale as the diagram. The steam line *E F* is drawn at the the time when the piston is subject to the full initial pressure. Following is the expansion curve, *F* to *G*, point of release, *G*,

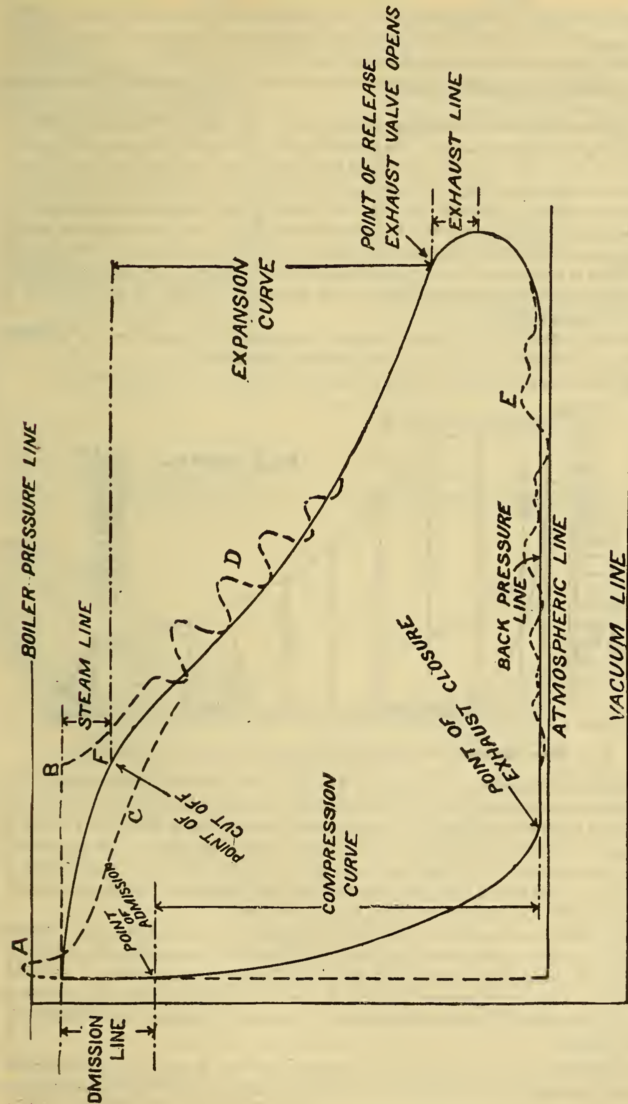


FIG. 179.—INDICATOR CARD NOMENCLATURE.

exhaust line *G H*, back pressure line, *H I*, and point of exhaust closure, *I*. The compression line *I J*, shows rising pressure, due to the compression of the steam remaining in the cylinder after the exhaust valve has closed. *J E* shows rise of pressure, due to admission of steam to the cylinder by the opening of the steam valve.

The mean effective pressure is represented in Fig. 180 by the mean height of the line *E F G H* above *H I J*. To determine its value from the diagram, divide the length *K B* into ten equal parts and from the *center* of these divisions, erect ordinates, as shown in Fig. 180, perpendicular to line *K B*. If the length of these ordinates which are enclosed between the sides of the diagram are measured by the steam pressure scale for the indicator spring used, and these lengths added together and divided by their number, the result will be the mean effective pressure. This is illustrated in the calculation on the diagram. The area can also be found by a planimeter or other means, and dividing the area by the length *K B* will give mean height.

Having determined the mean effective pressure, the horse-power of engines can be determined by use of table and formula on page 215.

Ideal curves for different types of engines are given in Figs. 181 to 189.

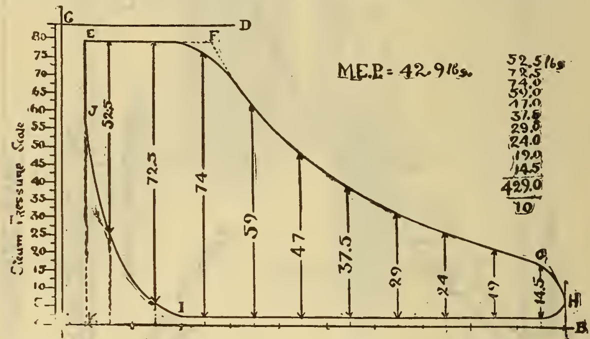


FIG. 180.—METHOD OF CALCULATING MEAN EFFECTIVE PRESSURE.

Combined diagrams of Compound Engines.—The only way of making a correct combined diagram from the indicator-diagrams of the several cylinders in a compound engine is to set off all the diagrams on the same horizontal scale of volumes, adding the clearances to the cylinder capacities proper. When this is done, the successive diagrams fall exactly into their right places relatively to one another, and would compare properly with any theoretical expansion curve. (Prof. A. B. W. Kennedy, Proc. Inst. M. E., Oct. 1886.)

Fig. 190 shows a combined diagram of a quadruple-expansion engine, drawn according to the usual method, that is the diagrams are first reduced in length to relative scales that correspond with the relative piston displacement of the three cylinders. Then the diagrams are placed at such distances from the clearance line of the proposed combined diagram as to correctly represent the clearance in each cylinder.

Clearance.—The clearance of an engine may be measured by filling with vaseline, the space between the piston and cylinder head when the engine is on centers and the volume of vaseline required to fill the space measured. This vol-

FIG. 181.—FRICTION INDICATION SIMPLE VALVE ENGINE.

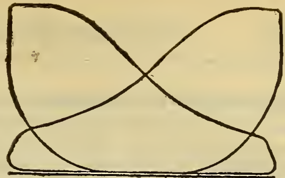


FIG. 182.—FULL LOAD INDICATION SIMPLE VALVE ENGINE.

FIG. 183.—INDICATION OF FRICTION FOUR VALVE ENGINE.

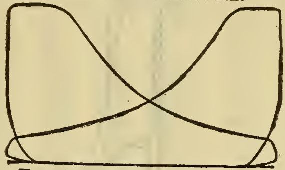


FIG. 184.—FULL LOAD OF FOUR VALVE ENGINE.

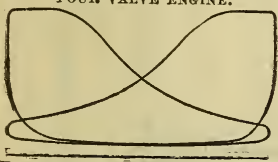


FIG. 185.—HIGH PRESSURE CARD FOR FOUR VALVE COMPOUND ENGINE.

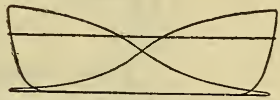


FIG. 186.—LOW PRESSURE CARD FOR FOUR VALVE COMPOUND ENGINE.

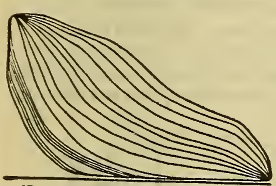


FIG. 187.—GRADUATED LOAD INDICATION.

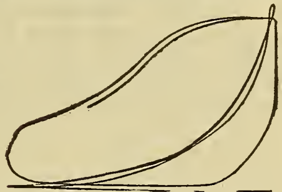


FIG. 188.—MAXIMUM AND MINIMUM INDICATION.

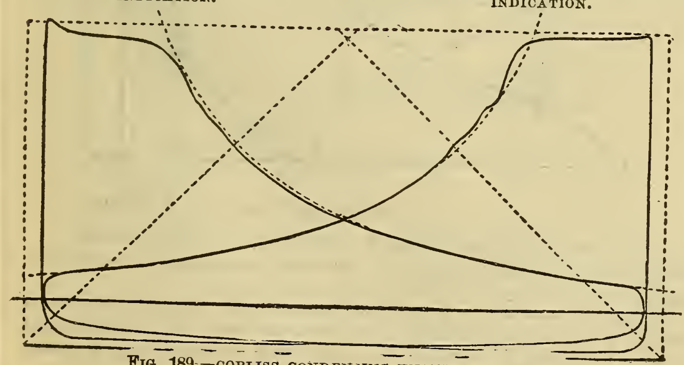


FIG. 189—CORLISS CONDENSING ENGINE INDICATION.

ume divided by the volume swept through by the piston per stroke, equals the per cent of clearance. In case the clearance can not be measured in this way, it may be roughly drawn from an indicator card by the following process. Draw a straight line, *c b a d*, across the compression curve, first having drawn *O X*, Fig.

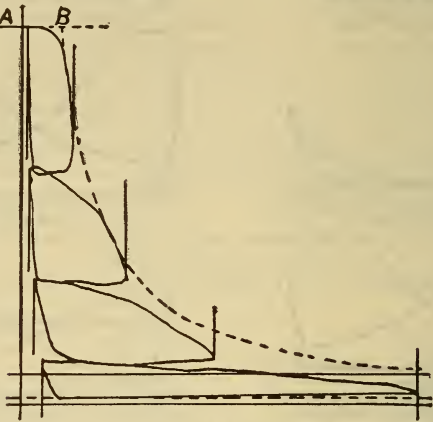


Fig. 190.—COMBINING MULTIPLE EXPANSION ENGINE DIAGRAMS.

191, parallel to the atmospheric line and 14.7 lbs. below. Measure from *a* the distance, *a d* equal to *c b*, and draw *Y O* perpendicular to *O X* through *d*; then will *T B* divided by *A T* be the percentage of clearance. The clearance may also be found from the expansion line by constructing a rectangle *e f h g*, and drawing

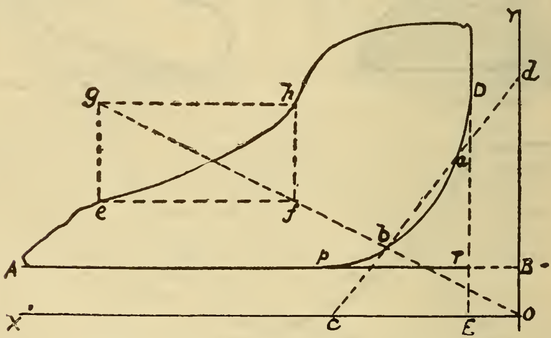


Fig. 191.—METHOD OF OBTAINING CLEARANCE LINES FROM DIAGRAM.

a diagonal *g f* to intersect the line *O X*. This will give the point, *O*, and by erecting a perpendicular to *O X* we obtain a clearance line *O Y*.

Both these methods for finding the clearance require that the expansion and compression curves be hyperbolas. Prof. Carpenter (*Power*, Sept. 1893) says that with good diagrams the methods are usually very accurate, and give results which check satisfactorily.

HORSE-POWER PER POUND MEAN EFFECTIVE PRESSURE.

$$\text{Hp. per lb. M. E. P.} = \frac{\text{Area in sq. in.} \times \text{piston speed}}{33{,}000}$$

Diam. of Cylinder, ins.	Speed of Piston in Feet per Minute. 100	240	300	400	450	500	550	600	650	750
4	.038	.091	.114	.152	.171	.19	.209	.228	.247	.285
4½	.048	.115	.144	.192	.216	.24	.264	.288	.312	.360
5	.06	.144	.18	.24	.27	.30	.33	.36	.39	.450
5½	.072	.173	.216	.288	.324	.36	.396	.432	.468	.540
6	.086	.205	.256	.342	.385	.428	.471	.513	.555	.641
6½	.102	.245	.307	.409	.464	.512	.563	.614	.698	.800
7	.116	.279	.348	.466	.524	.583	.641	.699	.756	.874
7½	.134	.321	.401	.534	.602	.669	.735	.802	.869	1.002
8	.152	.365	.456	.608	.785	.761	.837	.912	.989	1.121
8½	.172	.413	.516	.688	.774	.86	.946	1.032	1.118	1.290
9	.192	.462	.577	.770	.866	.963	1.059	1.154	1.251	1.444
9½	.215	.515	.644	.859	.966	1.074	1.181	1.288	1.395	1.610
10	.238	.571	.714	.952	1.071	1.190	1.309	1.428	1.547	1.785
11	.288	.691	.864	1.152	1.296	1.44	1.584	1.728	1.872	2.160
12	.342	.820	1.025	1.366	1.540	1.708	1.880	2.050	2.222	2.564
13	.402	.964	1.206	1.608	1.809	2.01	2.211	2.412	2.613	3.015
14	.466	1.119	1.398	1.864	2.097	2.331	2.564	2.797	3.029	3.495
15	.535	1.285	1.606	2.131	2.409	2.677	2.945	3.212	3.479	4.004
16	.609	1.461	1.827	2.436	2.741	3.045	3.349	3.654	3.958	4.567
17	.685	1.643	2.054	2.739	3.081	3.424	3.766	4.108	4.450	5.135
18	.771	1.849	2.312	3.083	3.468	3.854	4.239	4.624	5.009	5.780
19	.859	2.061	2.577	3.436	3.865	4.295	4.724	5.154	5.583	6.442
20	.952	2.292	2.855	3.807	4.285	4.759	5.234	5.731	6.186	7.138
21	1.049	2.518	3.148	4.197	4.722	5.247	5.771	6.296	6.820	7.869
22	1.152	2.764	8.455	4.607	5.183	5.759	6.334	6.911	7.486	8.638
23	1.259	3.021	3.776	5.035	5.664	6.294	6.923	7.552	8.181	9.44
24	1.370	3.289	4.111	5.482	6.167	6.853	7.538	8.223	8.908	10.279
25	1.487	3.569	4.461	5.948	6.692	7.436	8.179	8.923	9.566	11.053
26	1.609	3.861	4.826	6.435	7.239	8.044	8.848	9.652	10.456	12.065
27	1.733	4.159	5.199	6.932	7.799	8.666	9.532	10.399	11.265	12.998
28	1.865	4.477	5.596	7.462	8.395	9.328	10.261	11.193	12.125	13.991
29	2.002	4.805	6.006	8.008	9.009	10.01	11.011	12.012	13.013	15.015
30	2.142	5.141	6.426	8.568	9.639	10.71	11.781	12.852	13.923	16.065
31	2.288	5.486	6.865	9.144	10.287	11.43	12.573	13.716	14.866	17.145
32	2.436	5.846	7.308	9.744	10.962	12.18	13.398	14.616	15.834	18.270
33	2.590	6.216	7.770	10.360	11.655	12.959	14.245	15.54	16.835	19.425
34	2.746	6.59	8.238	10.984	12.357	13.73	15.103	16.476	17.849	20.595
35	2.914	6.993	8.742	11.656	13.113	14.57	16.027	17.484	18.941	21 855
36	3.084	7.401	9.252	12.336	13.878	15.42	16.962	18.504	20.046	23.130
37	3.253	7.819	9.774	13.032	14.861	16.29	17.919	19.548	21.177	24.435
38	3.436	8.246	10.308	13.744	15.462	17.18	18.898	20.616	22.334	25.770
39	3.620	8.648	10.86	14.48	16.29	18.1	19.91	21.62	23.53	27.150
40	3.808	9.139	11.424	15.232	17.136	19.04	20.944	22.848	24.752	28.560
41	4.002	9.604	12.006	16.008	18.009	20.00	22.011	24.012	26.013	30.015
42	4.198	10.065	12.594	16.792	18.901	20.99	23.089	25.188	27.287	31.485
43	4.40	10 56	13.20	17.6	19.8	22.00	24.2	26.4	28.6	33.00
44	4.606	11.046	13.818	18.424	20.727	23.03	25.333	27.636	29.939	34.545
45	4.818	11.563	14.454	19.272	21.681	24.09	26.399	28.908	31.317	36.135
46	5.043	12.086	15.128	20.144	22.662	25.18	27.698	30.216	32.754	37.770
47	5.256	12.614	15.768	21.024	23.652	26.28	28.908	31.536	34.164	39.420
48	5.482	12.846	16.446	21.928	24.669	27.41	30.151	33.152	35 633	41.115
49	5.714	12.913	17.142	22.856	25.713	28.57	31.427	34.284	37.141	42.855
50	5.950	14.28	17.85	23.8	26.775	29.75	32.725	35.7	38.675	44.625
51	6.180	14.832	18.54	24.76	27.855	30.95	34.045	37.08	40.205	46.425
52	6.432	15.437	19.296	25.728	28.944	32.16	35.376	38.592	41.808	48.240
53	6.684	16.041	20.052	26.736	30.078	32.42	36.762	40.104	43.446	50.130
54	6.940	16.656	20.82	27.76	31.23	33.7	38.17	41.64	45.11	52.05
55	7.198	17.275	21.594	28.792	32.391	35.99	39.589	43.188	46 787	53.985
56	7.462	17.909	22.386	29.848	33.579	37.31	41.041	44.772	48.503	55.965
57	7.732	18.557	23.196	30.928	34.794	38.66	42.526	46.392	50.258	57.99
58	8.006	19.214	24.018	32.024	36.027	40.03	44.033	48.036	52.039	60.045
59	8.284	19.902	24.852	33.136	37.278	41.42	45.562	49.704	53.846	62.13
60	8.356	20.558	25.698	34.264	38.547	42.83	47.113	51.396	55.679	64.245

TRUE RATIO OF EXPANSION AS AFFECTED BY CUT-OFF AND CLEARANCE.

True Ratio of Expansion.	PER CENT OF CLEARANCE.									
	1	2	3	4	5	6	7	8	9	10
	PER CENT OF CUT-OFF.									
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1¼	.789	.796	.794	.792	.790	.787	.785	.783	.781	.780
1½	.663	.660	.657	.654	.650	.646	.643	.640	.636	.633
1¾	.567	.563	.559	.555	.550	.545	.541	.537	.533	.528
2	.495	.490	.485	.480	.475	.470	.465	.460	.455	.450
2¼	.439	.433	.428	.423	.417	.411	.406	.400	.395	.389
2½	.394	.388	.382	.376	.370	.364	.358	.352	.346	.340
2¾	.358	.351	.345	.338	.332	.325	.319	.313	.306	.300
3	.327	.320	.313	.307	.300	.293	.287	.280	.273	.267
3½	.279	.271	.265	.257	.250	.243	.236	.228	.221	.214
4	.243	.235	.227	.220	.212	.205	.197	.190	.182	.175
4½	.215	.207	.199	.191	.183	.175	.168	.160	.152	.144
5	.192	.184	.176	.168	.160	.152	.144	.136	.128	.120
5½	.174	.165	.157	.149	.141	.132	.125	.116	.108	.100
6	.158	.150	.142	.133	.125	.116	.108	.100	.092	.083
6½	.145	.137	.128	.120	.112	.103	.095	.086	.078	.069
7	.134	.126	.117	.109	.100	.091	.083	.074	.066	.057
7½	.125	.116	.107	.099	.090	.081	.073	.064	.055	.047
8	.116	.108	.099	.090	.081	.072	.064	.055	.046	.037
8½	.109	.100	.091	.082	.074	.065	.056	.047	.038	.029
9	.102	.093	.084	.076	.067	.058	.049	.040	.031	.022
9½	.096	.087	.078	.070	.060	.052	.043	.034	.025	.....
10	.091	.082	.073	.064	.055	.046	.037	.028	......	....
10½	.086	.077	.068	.059	.050	.041	.032	.023	......	....
11	.082	.073	.064	.055	.045	.036	.027	......	......	.....
11½	.078	.069	.060	.050	.041	.032	.023	......	......	.....
12	.074	.065	.056	.047	.037	.028	......	......	......	.....
13	.068	.058	.049	.040	.031	.021	......	......	......	.....
14	.062	.053	.044	.034	.025	......	......	......	......	.....
15	.057	.048	.039	.029	.020	......	......	......	......	.....
16	.053	.044	.034	.025	......	......	......	......	......	....
17	.049	.040	.031	.021	......	......	......	......	......	.....
18	.046	.037	.027	......	......	......	......	......	......	.....
19	.043	.034	.024	......	......	......	......	......	......	.....
20	.040	.031	.021	......	......	......	......	......	......	.....

COMPRESSION OF STEAM IN THE CYLINDERS.

BEST PERIODS OF COMPRESSION; CLEARANCE 7 PER CENT.

Cut-off in Percentages of the Stroke.	TOTAL BACK PRESSURE, IN PERCENTAGES OF TOTAL INITIAL PRESSURE.							
	2½	5	10	15	20	25	30	35
	PERIODS OF COMPRESSION, IN PARTS OF THE STROKE.							
10%	65%	57%	44%	32%	....	....	....	....
15	58	52	40	29	23%	....	....	....
20	52	47	37	27	22	....	....	....
25	47	42	34	26	21	17%	....	....
30	42	39	32	25	20	16	14%	12%
35	39	35	29	23	19	15	13	11
40	36	32	27	21	18	14	13	11
45	33	30	25	20	17	14	12	10
50	30	27	23	18	16	13	12	10
55	27	24	21	17	15	13	11	9
60	24	22	19	15	14	12	11	9
65	22	20	17	15	14	12	10	8
70	19	17	16	14	14	12	10	8
75	17	16	14	13	12	11	9	8

STEAM CONSUMPTION DISTRIBUTION AND VARIOUS EFFICIENCIES OF AVERAGE ENGINES FROM 200 TO 500 H. P.

Engine Class.	Steam Gage Pressure. Lbs.	Dry Steam Consumption, Lbs. per 1 H. P. hour.			Thermal Efficiency. Per Cent.	Engine Efficiency. Col. 3 ÷ Col. 5. Per Cent.	Indicated Commercial Efficiency Col. 6 x Col. 7. Per Cent.	Mechanical Efficiency Per Cent. Inc. Cond.	Brake Commercial Efficiency. Col. 8 x Col. 9. Per Cent.
		Standard Engine.	Minimum Waste.	Minimum Actual Consumption.					
NON-CONDENSING.									
Throttling, small	80	17.83	27.17	45	14.29	39.7	5.67	85.	4.82
Simple, Dep. Valve....	100	16.08	16.92	33	15.77	48.75	7.65	94	7.19
Compound Dep. Valve.	130	14.30	9.70	24	17.62	59.6	10.50	92	9.66
Simple Indep. Valve....	100	16.08	11.92	28	15.77	59.5	9.05	92	8.32
Compo'nd Indep. Valve	130	14.30	7.70	22	17.62	65.	11.44	90	9.28
CONDENSING.									
Simple Dep. Valve.....	100	8.81	18.19	27	26.50	32.65	8.65	91	7.87
Compound Dep. Valve.	130	8.27	11.73	20	28.14	41.35	11.63	90	10.48
Triple Dep. Valve......	160	7.85	9.15	17	29.44	46.2	13.61	90	12.25
Simple Indep. Valve....	100	8.81	13.19	22	26.50	40.05	10.61	88	9.35
Compo'nd Indep. Valve	130	8.27	9.73	18	28.14	45.95	12.91	87	11.23
Triple Indep. Valve.....	160	7.85	7.15	15	29.44	52.4	15.43	87	13.43
Comp. or Triple Indep. Valve, very large.....	170	7.74	5.26	13	29.85	59.5	17.77	92	16.35

Note: The condenser pressure is assumed at 2 lbs. absolute.

PRACTICAL ECONOMY OF CENTRAL STATION OPERATION.

SIMPLE, HIGH-SPEED, NON-CONDENSING ENGINES.

Boilers.	Hours in run.	Average K. W. while running.	Watt hours per day.	Lbs. of coal per day.	Kind of coal used.	Lbs. of water per lb. of coal.	Lbs. of Steam per 1 HP. hour. Tested.	Lbs. of Steam per 1 HP. hour. Calculated including Auxiliaries and Losses.	Lbs. of Coal per 1 HP. H. (Includes everything.)	Lbs. of Coal per K. W. H. (Includes everything.)	Watt hours per lb. of coal.
Horizontal Tubular............	24	34.4	825,000	5,022	Bit. and Hard Screenings...........	10.35	......	38.1	3.68	6.1	164
Hor. T. and Hor. W. T.........	24	112.	2,683,008	21,571	Bit. Nut and Slack..................	....	......	....	4.86	8.06	124
Horizontal Tubular............	24	81.7	1,960,973	17,600	Bit..................................	....	......	....	5.43	9.00	111
Hor. T. and Hor. W. T.........	24	283.	2,794,304	62,504	.6 Anth. and .4 Bit..................	....	......	....	5.53	9.17	109
Horizontal Tubular............	....	....	228,440	3,041	Bit. Run of Mine....................	....	......	....	6.35	10.52	95
" "	13½	90.1	1,217,000	12,895	Anth..................................	....	......	....	6.42	10.63	94
" "	...	....	268,800	2,896	Bellwood Bit.........................	5.1	......	33.4	6.55	10.87	92
" "	14	34.1	477,425	5,400	Semi-Bit.............................	9.68	37	66.3	6.85	11.37	88
" "	10	50.7	506,697	6,296	Bit. Slack...........................	5.59	......	42.1	7.53	12.5	80
" "	8	55.5	444,193	6,101	" "	4.66	......	38.5	8.26	13.7	73
Hor. T. and Vert. W. T........	24	60.3	1,444,931	20,800	Slack................................	6.33	......	55.3	8.74	14.5	69
Horizontal Tubular............	8	28.7	230,187	3,600	....	....	......	....	9.4	15.61	64
" "	14¾	21.1	310,928	5,000	Bit..................................	....	......	....	9.71	16.12	62
" "	7½	27.3	204,435	3,600	"	....	......	....	10.56	17.53	57
" "	14	11.2	156,800	2,800	Bit. Run of Mine....................	....	......	....	10.77	17.85	56
" "	7½	28.6	214,485	3,900	Bit..................................	....	......	....	10.77	17.85	56
" "	7½	29.	217,288	4,000	"	....	......	....	11.15	18.5	54
" "	7	31.6	221,250	4,200	"	....	......	....	11.3	18.85	53
" "	7	29.8	208,538	3,900	"	....	......	....	11.3	18.85	53
" "	6	26.9	161,458	3,150	"	....	......	....	11.8	19.6	51
" "	7½	24.8	186,412	3,810	Slack................................	....	......	....	12.3	20.4	49
" "	7½	23.3	174,928	3,720	Bit..................................	....	......	....	12.8	21.25	47
" "	15½	52.1	806,880	19,300	Bit. Slack...........................	5.78	......	82.8	14.33	23.8	42
" "	18	72.	1,294,708	31,040	" "	4.23	......	60.7	14.53	23.8	42
" "	14	54.5	762,825	20,700	" "	5.44	......	88.5	15.28	27.	37

SLOW-SPEED SIMPLE.										
Horizontal Tubular	13	162.	2,103,800	16,800	Anth. Buckwheat	6.84	26	33.	4.82	8.	125
Vertical Water Tube	14½	130.	1,881,102	31,992	Bit. and No. 2 Nut	5.8	......	59.4	10.23	17.	59
Horizontal Tubular	10	645.	6,453,491	116,000	Bit. and Slack	.....	......	....	10.75	17.85	56
Vertical Water Tube	14	104.	1,454,656	31,739	Bit. and No. 2 Nut	5.48	......	71.8	13.1	21.75	46
HIGH-SPEED COMPOUND.											
Vertical Water Tube	14	195.2	2,734,976	19,900	Slack	8.25	......	36.3	4.4	7.3	137
" " "	14	185.5	2,599,705	19,050	"	7.92	......	35.1	4.43	7.35	136
" " "	14	194.5	2,722,463	20,650	"	7.8	......	35.1	4.5	7.46	134
Horizontal Water Tube	24	120.	2,879,000	31,200	Bit. Screenings	.....	......	....	6.55	10.87	92
Horizontal Tubular	15	17.	254,745	4,520	Bit	.....	......	....	10.77	17.87	56
HIGH-SPEED SIMPLE CONDENSING ENGINE.											
Horizontal Tubular	6½	14.4	93,541	1,365	Buckwheat Anth	.....	......	....	8.86	14.7	68
" "	15	13.57	203,555	6,200	" "	.....	......	....	18.25	30.3	33
HIGH-SPEED COMPOUND.											
Horizontal Tubular	24	133.5	3,207,392	11,600	Bit. Lump	6.2	......	15.72	2.54	4.22	237
" "	24	99.8	2,397,712	11,251	" "	5.7	......	16.12	2.83	4.7	213
" "	16½	43.1	711,720	5,100	Bit. Slack	.....	......	....	4.3	7.14	140
" "	16½	44.2	727,720	5,200	Bit.	.....	......	....	4.3	7.14	140
" "	16	95.5	1,528,100	11,595	Bit. Lump	.....	......	....	4.6	7.63	131
" "	15½	44.9	695,720	5,300	Bit	.....	......	....	4.6	7.63	131
Horizontal Water Tube	9½	47.8	454,058	4,831	Slack	.....	......	....	6.4	10.63	94
SLOW-SPEED SIMPLE.											
Horizontal Tubular	14½	85.8	1,243,441	14,224	Bit.	.....	......	....	6.33	11.5	87
" "	14	85.8	1,201,483	15,386	"	.....	......	....	7.72	12.8	78
SLOW-SPEED COMPOUND.											
Hor. W. T. and Hor. Tubular	24	210.5	5,053,166	28,050	½ Anth. and ¼ Pea and Dust	8.91	......	29.9	3.35	5.56	180
Horizontal Tubular	24	50.5	1,212,900	7,105	Bit. Run of Mine	.....	......	....	3.52	5.85	171
" Water Tube	24	141.6	3,398,595	20,300	½ Anth. and ½ Bit	6.6	......	23.8	3.61	5.99	167
" " "	24	140.5	3,373,305	20,300	" " "	6.2	......	22.5	3.63	6.03	166
" " "	24	140.2	3,366,065	20,300	" " "	6.82	......	24.7	3.63	6.03	166
Hor. W. T. and Hor. Tubular	24	178.	4,270,077	26,600	½ Anth. and ½ Pea and Dust	9.17	......	34.3	3.74	6.21	161
Vertical Water Tube	24	673.	16,149,010	121,400	Slack and Bit	.....	......	....	4.53	7.52	133
Horizontal Tubular	16	96.8	1,549,100	11,860	Bit. Run of Mine	7.7	......	35.4	4.6	7.64	131
" "	16	98.1	1,568,600	12,000	Bit. Lump	7.7	......	35.4	4.6	7.64	131
TRIPLE EXPANSION.											
Horizontal Water Tube	24	1100.	26,402,256	124,383	½ Bit. and Anth. Screenings	7.38	18	20.95	2.84	4.72	212
" " "	24	1677.	40,230,300	213,000	Bit. and Screenings	.....	15½	....	3.13	5.29	189

REQUISITE WEIGHT OF STEAM PER 1 HP-HOUR AND THERMAL EFFICIENCY OF STANDARD ENGINES.

Lbs. Absolute Steam Pressure.	Non-Condensing Engines, Air Pressure, 14.7 lbs. Absolute.		Condensing Engines. Lbs. Absolute Pressure in Condenser.									
			1		2		3		4		5	
	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. hour.	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. hour.	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. hour.	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. hour.	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. Hour.	Thermal Efficiency, per cent.	Lbs. Dry Steam per 1 H. P. hour.
75	12.51	20.45	26.8	8.60	23.6	9.98	21.6	11.07	20.1	12.00	18.9	12.90
80	12.95	19.75	27.2	8.46	24.07	9.77	22.07	10.82	20.55	11.73	19.38	12.56
85	13.40	19.05	27.55	8.35	24.44	9.62	22.5	10.60	21.00	11.47	19.8	12.27
90	13.86	18.40	27.95	8.22	24.84	9.45	22.9	10.40	21.4	11.23	20.22	12.01
95	14.29	17.83	28.3	8.11	25.20	9.32	23.3	10.21	21.8	11.03	20.62	11.75
100	14.68	17.32	28.65	8.00	25.60	9.19	23.62	10.06	22.2	10.81	21.00	11.53
105	15.06	16.89	28.97	7.91	25.90	9.04	23.98	9.91	22.5	10.65	21.35	11.33
110	15.40	16.48	29.3	7.81	26.22	8.91	24.3	9.76	22.85	10.48	21.70	11.14
115	15.77	16.08	29.55	7.73	26.50	8.81	24.6	9.64	23.15	10.32	22.00	10.98
125	16.45	15.40	30.13	7.57	27.10	8.60	25.2	9.39	23.75	10.05	22.6	10.66
135	17.05	14.81	30.61	7.45	27.6	8.44	25.8	9.16	24.3	9.82	23.18	10.38
145	17.62	14.30	31.1	7.32	28.14	8.27	26.25	8.98	24.85	9.57	23.70	10.14
155	18.14	13.89	31.5	7.20	28.6	8.10	26.7	8.82	25.3	9.40	24.20	9.92
165	18.61	13.51	31.95	7.10	29.0	7.99	27.2	8.64	25.8	9.20	24.63	9.72
175	19.10	13.12	32.35	7.00	29.44	7.85	27.6	8.51	26.2	9.04	25.1	9.53
185	19.55	12.82	32.7	6.92	29.85	7.74	28.0	8.37	26.6	8.90	25.55	9.36
200	20.15	12.42	33.22	6.80	30.35	7.61	28.53	8.20	27.2	8.69	26.1	9.15

STEAM PIPING.

The proper arrangement of piping in a station is such an important matter that the relative location of boilers and engines is largely considered with regard to their steam connections. In general, the live steam velocity should not exceed 6000 ft. to 8000 ft. per minute, the lower velocity being used with slow-speed engines; and 3 per cent drop may be allowed at the end of the steam main furthest from the boiler in a single line of pipe.

The method of calculating the proper size of steam pipe is to first estimate the effective length by adding to its actual length the number of globe valves, automatic relief valves, separators and T's where the direction of steam flow is changed, and multiply the sum by 5. Then add together all the right angle elbows, and multiply their sum by 3⅓, and add the number of Y's and T's through which the steam passes without turning, multiplying this sum by 1.6. The sum of these products thus found multiplied by the actual internal diameter of the pipe in inches, and the result in feet added to the actual length of pipe line will give the effective length. The diameter must be assumed and can be checked from the table, on this page.

By obtaining the foot run of pipe, as above, and the pounds of steam per hour at each position required on a single header system, and the pressure losses assigned to these different parts of the piping system, we can calculate the size of pipe. The pounds of steam per hour multiplied by the square root of the dividend obtained by dividing the effective length of pipe in feet by the pounds pressure to be lost gives from the table below, under the column of the initial pressure of steam, the nearest number to that obtained by applying the formula; which is the proper diameter.

CONSTANTS FOR FLOW OF STEAM IN PIPES.

Constants = Lbs. of Steam per Hour $\times \sqrt{\frac{\text{Ft. Run}}{\text{Lbs. Loss of Pressure.}}}$

Actual Internal Diam. of Pipe, Ins.	26 inch Vacuum.	Gage Pressure, Pounds per Square Inch. 2	100	120	140	160	180	200
1	228	620	1,530	1,650	1,760	1,870	1,960	2,060
2	1,110	3,020	7,450	8,070	8,590	9,110	9,580	10,000
3	3,960	10,800	26,600	28,800	30,700	32,500	34,200	35,900
4	8,390	22,900	56,400	61,100	65,000	68,900	72,500	76,000
5	15,200	41,500	102,500	110,800	118,000	125,000	132,000	138,000
6	23,800	65,000	160,000	173,000	185,000	196,000	206,000	216,000
7	35,400	96,500	238,000	258,000	275,000	291,000	306,000	321,000
8	50,000	136,000	336,000	364,000	388,000	411,000	432,000	453,000
9	67,700	185,000	456,000	493,000	525,000	557,000	585,000	615,000
10	88,700	242,000	597,000	645,000	687,000	730,000	765,000	805,000
11	113,000	308,000	762,000	822,000	877,000	930,000	978,000	1,025,000
12	141,000	384,000	948,000	1,027,000	1,094,000	1,158,000	1,217,000	1,280,000
13	172,000	470,000	1,160,000	1,255,000	1,340,000	1,420,000	1,490,000	1,560,000
14	208,000	567,000	1,400,000	1,510,000	1,610,000	1,710,000	1,800,000	1,890,000
15	247,000	675,000	1,670,000	1,800,000	1,920,000	2,040,000	2,140,000	2,240,000
16	290,000	793,000	1 960,000	2,110,000	2 260,000	2,390,000	2,510,000	2,640,000
17	339,000	925,000	2,280,000	2,470,000	2,630,000	2,790,000	2,930,000	3,080,000
18	392,000	1,070,000	2,640,000	2,860,000	3,040,000	3,230,000	3,390,000	3,560,000
19	449,000	1,220,000	3,020,000	3,260,000	3,480,000	3,690,000	3,880,000	4.060,000
20	512,000	1,390,000	3,440,000	3.720,000	3,970,000	4,210,000	4,420,000	4,640,000
21	579,000	1,580,000	3,900,000	4,210,000	4,490,000	4,760,000	5,010,000	5,250,000
22	651,000	1,770,000	4.370,000	4.730.000	5.040,000	5,340,000	5,610.000	5,900,000
23	728,000	1,980,000	4,900,000	5,300,000	5,650,000	5,990,000	6,300,000	6,610,000

A loop system of piping, Fig. 192, is installed to give two methods of feeding from the boilers. In this case one side of the loop should be able to carry two-thirds of the aggregate steam demand. If there were liability of a breakdown the loop system is very effective, as repairs on the piping plant can be made while steam is kept constantly on the mains. Statistics on steam pipe breakdowns in railway stations, show a permanent structure with such a remote liability of breakdown that the additional first cost and constant condensation cost is not compensated for. Large plants may be built up on the unit system with a single main, Fig. 193, or the combination system, Fig. 194. A system of smaller pipes shows less first cost than a single large steam main. It is doubtful whether it is profitable to exceed a 24-in main for pressures over 100 lbs. per square inch.

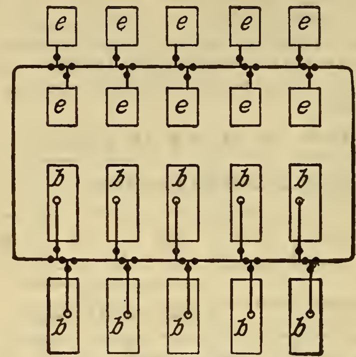


FIG. 192.—LOOP SYSTEM.

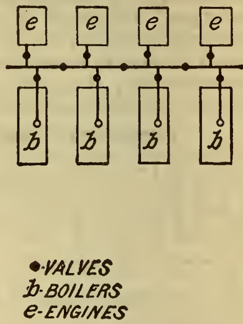


FIG. 193.—UNIT SYSTEM.

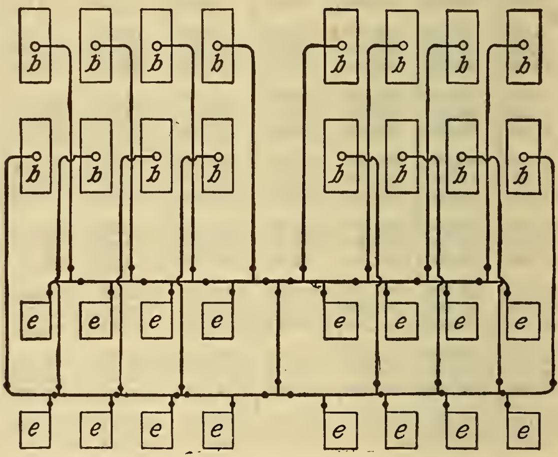


FIG. 194.—COMBINATION SYSTEM.

In railway work the pounds of steam assumed for pipe calculation should be in excess of the average hourly demand, for the reason that the overload falls on all engines working in multiple and a fall in pressure varies as the square of the rate of flow, thus affecting the regulation of the engine. The steam pipe, if short, should contain at least twenty times the volume of the engine cylinders fed from

STEAM PIPES.

Velocity of Steam in Pipes Corresponding to a Constant Pressure Loss.

Actual Internal Diam. of Pipe, Ins.	26 inch Vacuum.	Gage Pressure, Pounds per Square Inch.						
		2	100	120	140	160	180	200
	Velocity, Feet per Minute at 1 lb. Loss of Pressure per 100 feet.							
1	12,110	4,440	1,800	1,667	1,561	1,475	1,403	1,338
2	18,070	6,625	2,680	2,482	2,325	2,197	2,090	1,992
3	23,450	8,600	3,482	3,230	3,020	2,855	2,716	2,590
4	27,850	10,230	4,140	3,835	3.590	3,390	3,230	3,080
5	32,420	11,900	4,815	4,460	4,175	3,945	3,750	3,580
6	35,300	12,930	5,230	4,850	4,540	4,290	4,080	3,890
7	38,550	14,130	5,720	5,300	4,960	4,690	4,460	4,255
8	41,600	15,270	6,175	5,720	5,360	5,060	4,820	4.590
9	44,500	16,330	6,605	6,120	5,730	5,415	5,150	4,910
10	47,250	17,320	7,010	6,500	6,085	5,750	5,470	5,210
11	49,750	18,250	7,380	6,845	6,410	6,050	5,760	5,490
12	52,100	19,110	7,730	7,170	6,710	6.340	6,030	5,755
13	54,300	19,910	8.050	7,470	6,990	6,610	6,290	6,000
14	56,500	20,690	8,375	7,760	7,270	6,870	6,530	6,225
15	58,600	21,500	8,700	8,060	7,550	7,130	6,780	6,470
16	60,550	22,200	8,980	8,330	7,800	7,370	7,000	6,685
17	62,500	22,950	9.280	8,600	8,050	7,605	7,235	6,900
18	64,500	23,650	9,570	8,860	8,300	7,840	7,460	7,110
19	66,250	24,300	9,830	9,110	8,530	8,060	7 660	7,310
20	68,100	24,950	10,110	9,370	8,770	8,280	7,880	7,510
21	69,950	25,600	10,390	9,620	9,000	8,500	8,090	7,715
22	71,600	26,250	10,630	9.850	9,210	8,710	8,290	7,900
23	73,250	26,850	10,890	10,080	9,440	8,910	8,480	8,080

it. Engines that staggered badly have been cured by adding local steam storage where there was a throttling action of the steam main for instantaneous demands. This is more noticeable in slow-speed than in high-speed engines.

As an example of pipe design, we may take a 1000 ihp condensing engine with 120 lbs. boiler pressure. As we may under peculiar circumstances desire to run non-condensing at full load, the live steam and atmospheric exhaust pipes should be designed to carry 23,000 lbs. per hour, assuming 23 lbs. of steam per hp-hour. Overloads if they come are cared for by raising the boiler pressure, as the engine is not intended for regular non-condensing running, but the condenser exhaust should be proportioned for 25 per cent overload—that is, 1225 ihp at about 16 lbs. per hp-hour or a total of 19,600 lbs. per hour. Assume the total length of steam pipe to be 75 ft. and that there is one separator, one globe valve and four sharp right elbows in the line. We thus have (boiler entrance 1, separator 1, globe valve 1 = 3) × 5 = 15. Also 3⅓ × 4 elbows = 13⅓, and the total sum is 28. Assuming D at 8 ins. we have 75 ft. + (8 × 28) = 299 ft. effective

Velocity of Steam in Pipes Corresponding to Weight of Steam Delivered per Hour.

Actual Internal Diam. of Pipe, Ins.	26 inch Vacuum.	Gage Pressure, Pounds per Square Inch.						
		2	100	120	140	160	180	200
	Velocity, Feet per Minute, per Pound of Steam Delivered per Hour.							
1	532.	71.5	11.74	10.1	8.84	7.89	7.13	6.48
2	133.	17.9	2.935	2.52	2.21	1.97	1.78	1.62
3	59.1	7.94	1.305	1.12	.982	.877	.792	.72
4	33.2	4.47	.734	.631	.553	.493	.446	.405
5	21.3	2.86	.470	.404	.354	.316	.285	.259
6	14.8	1.99	.327	.281	.246	.219	.198	.180
7	10.85	1.46	.240	.206	.180	.161	.145	.132
8	8.30	1.12	.183	.158	.138	.123	.111	.101
9	6.56	.881	.145	.125	.109	.0972	.0880	.0799
10	5.32	.715	.117	.101	.0884	.0789	.0713	.0648
11	4.40	.590	.0971	.0835	.0730	.0651	.0589	.0535
12	3.70	.497	.0816	.0702	.0614	.0548	.0496	.0450
13	3.15	.423	.0695	.0598	.0523	.0467	.0422	.0384
14	2.72	.365	0599	.0515	.0451	.0402	.0364	.0330
15	2.36	.318	0522	.0449	.0393	.0350	.0317	.0288
16	2.08	.280	.0458	.0394	.0345	.0308	.0279	.0253
17	1.84	.248	0407	.0350	.0306	.0273	.0247	.0225
18	1.64	.220	0362	.0312	.0273	.0243	.0220	.0200
19	1.47	.198	.0326	.0280	.0245	.0218	.0198	.0180
20	1.33	.179	.0294	.0252	.0221	.0197	.0178	.0162
21	1.21	.162	.0278	.0239	.0200	.0179	.0162	.0152
22	1.10	.148	.0243	.0209	.0183	.0163	.0147	.0134
23	1.00	.135	.0222	.0191	.0167	.0149	.0135	.0122

length. Three per cent pressure loss is 3.6 lbs.; and $\sqrt{\frac{299}{3.6}} = 8.89$ per pound × 23,000 lbs. = 204,000.

We find in table, page 221, that this corresponds to a little more than a 6-in. pipe. Assuming the pipe to be 6 ins. and calculating over again we get an effective length of 242 ft. and a constant of 188,000, corresponding to a pipe just larger than 6 ins. If the globe valve was replaced by a gate valve, and long sweep elbows used, the effective length would be 95 ft. and the corresponding diameter is just 1 in. smaller; the construction cost would be 20 per cent less, and the condensation would be 17 per cent less than with the other fittings and larger pipe.

Material and Sizes of Steam Piping.—Wrought iron pipe and cast-iron fittings are generally used. The pipe is made in "standard weight," "extra strong" and "double extra strong" grades. Fittings are "light weight," "standard weight" and "extra heavy" grades. All pipe and fittings are rated by "nominal inside diameter" of pipe up to and including 12 ins. There is no 13 in. size, and all material above 12 ins. is rated by the actual outside diameter, and so specified. Thus a pipe 13.25 ins. inside diameter is called "14 in. O. D," and the next size "15 in. O. D." "Standard" pipe should be proved to 300 lbs. per sq. in. hydraulic pressure in sizes up to 1¼ in., and to 500 lbs. in larger sizes. Pipe should be good for a working pressure of half its proof pressure. Thus "standard weight" pipe is generally used; but on account of insufficient thickness at the threads, for 1 in., 2½ in. and 3 in. pipe, if a strong job is desired, especially at boilers and main line taps, "extra strong" is generally specified.

Brass pipe is generally used around machinery for gages and oiling systems on account of the ease of bending, better finish and less liability to leak with oil than iron pipe. Copper pipe is used for long sweeps and expansion bends, the pipe generally being riveted and brazed to brass flanges. Soft steel pipe is used where the pipe has to be flanged over the flange ends, and is an alternative for copper pipe in long sweeps or expansion bends.

Fittings.—In regard to fittings, "light weight" is good for 25 lbs. pressure and is therefore used for atmospheric exhaust work. Double, galvanized, spiral-riveted, flanged-iron pressure pipes are also used for this work. For condenser exhaust work it may also be used, but the real trouble with light weight fittings is the liability of breakages in making the flanges on the pipe and drawing them up tight if there is any strain due to poor alignment. "Standard weight" is very satisfactory for exhaust work and steam pressures below 100 lbs., though it is often used up to 150 lbs., the only objection being that it is difficult to get the flanges tight enough together for high pressure work without breaking the bolts. There is an objection to the extra heavy fittings, in that the number of bolt holes in most of the flanges are not even multiples of 4, and in some cases are an odd number. This arrangement makes a quarter turn impossible.

Valves.—Valves are of "globe" and "gate" patterns, the seats being made of a variety of metals. Bronze seats give very good results for globe and gate valves; but exhaust gate valves, and valves seldom used, may have babbitt seats in order to reduce the cost. It is advantageous to have the seats renewable. Valves with outside screw and yoke are often made with a cone top on the stem just under the gland, the top and corresponding seat being ground. This makes it possible to pack the gland under pressure by opening the valve wide. On account of the collection of dirt or scale on the stem seat, the valve may blow too much for packing under pressure.

Valve seats as well as all piping should be cleaned just before erection, and after erection steam blown through them to the air in order to remove unavoidable dirt. To close a valve no attempt should be made to screw the gate down harder than the manual effort of the handwheel, for it generally results in marring the seat or twisting the stem. A clot of water suddenly released has sufficient velocity given it with steam behind it to break cast fittings, therefore care must be taken in opening valves. Babbitt seat valves for condenser exhaust work should be by-passed for 20 ins. and over. Atmospheric exhaust valves do not need by-passes. Bronze seat valves should be by-passed at 12 ins. or 14 ins. and over for 100 lbs., at 8 ins. or 10 ins. for 150 lbs., and at 6 ins. or 8 ins. for 200 lbs. pressure.

In opening up pipe or fittings shut off from the steam supply by valves, some positive means should be taken to learn that the valves are not leaking dangerously; therefore before risking the opening of the pipe line, drill a ¼-in. hole in the pipe, which can afterwards be plugged.

Steam Pipe Joints.—Tight joints are the combined result of good design and workmanship. The screw threads should be perfect. Where flanges are used they should be made up tight, and the pipe ends should not come flush with their faces. All threads, flange faces and gaskets, but not ground faces, should be painted before assembling. For work that is permanent Caliban's cement is very satisfactory, or graphite mixed with boiled linseed oil. If these are not convenient, a mixture of 2 of white lead to 1 of red lead in boiled linseed oil is very good. Red lead alone is liable to crack under strains. In any case the paint should not be thin and should be thoroughly and uniformly applied with a brush over the abutting surfaces.

Small pipes are joined throughout with screw couplings, but large pipes should have flange joints at all fittings, and screw couplings elsewhere. Light and medium pressure flanges are screwed on the pipe, and have plain faces. High-pressure flanges are screwed or welded on to the pipe ends, or else the latter are flared over the flange faces and expanded into recesses in their hubs, the portion of the pipe flared over being usually finished for a ground joint. Where ground joints are not used it leads to better results to have the flange faces tongued and grooved.

Square-head bolts and hexagon nuts are preferable, and wrenches or spanners for them should have hardened surfaces and be extra strong so that a small pipe may be used as a lever. A hammer should not be used to turn the wrench. Where cap bolts have to be used, as in attaching to separators, etc., they should have a hexagon head; and considerable care has to be used before assembling, to see that the bolts are an easy fit, and afterwards that they do not break or strip the thread.

Gaskets cut out of sheet packing may be used where they are not liable to blow out, as on exhaust pipes and inside the tongue of high pressure flanges, but corrugated copper gaskets are not expensive and are more easily applied and generally better, though in some cases the superior elasticity of heavy sheet packing may stop a leak, even in a live steam pipe, where copper fails. The hole diameter of gaskets should be between the inside and outside pipe diameters. The outside diameter should be equal to the inside of the bolt-hole diameter for copper gaskets and the outside flange diameter for sheet packing unless tongued and grooved flanges are used, in which case it should equal the inside tongue diameter. Tongued and grooved flanges may also be packed at the bottom of the groove with asbestos or sheet packing. In any case gaskets or packing should have no radial cuts.

If flange faces are found to leak after the steam is on, the pressure should be entirely relieved before attempting to tighten them. If screw threads are found to leak they may sometimes be caulked with soft copper wire with the pressure on or off as desired.

Steam Pipe Supports.—Pipe hanging of the best order is absolutely necessary if tight joints are desired. Trouble with vibration is chiefly due to turns in the pipe being reacted upon by steam puffing through the steam main. Pipe is best hung from short rigid centers in such a manner that the pipe may move longitudinally under expansion strains due to heat, but not transversely under any conditions. Longitudinal vibration will be prevented by the shortness of the suspension radii.

Where pipe must be hung on a long radius from above, it may be successfully accomplished by a three-joint or four-joint suspension with the upper suspension ends well spread apart. The suspension rods should have turn buckles and must be provided with means to prevent their transverse vibration if they are very long.

Separators, Engine Drains, Etc.—Separators for oil or water depend for their success upon a few simple conditions. On the live steam side they should be placed as close to the engine as possible. In case dry steam is expected from the boilers, they should be pretty cheap, but if the boilers are expected to prime, no desirable quality should be omitted. Of course, in any case there is no use for them if they will not separate, but the cost is mainly dependent on the capacity and naturally this need not be so large where water is but a possible contingency as where it is a probable one. Large separators, if they can be placed near the engine, undoubtedly equalize the pressure and thereby help the speed regulation.

The qualifications of a good separator are that, in entering it, the steam shall immediately change its direction of flow and reduce its velocity. The water or oil having greater specific weight will not change so rapidly and may therefore be thrown to surfaces down which they may run to a receiving chamber. In doing so they should not leave the surface or be blown along it into the current of steam. After reaching the receiving chamber they should be protected from violent waves or rotary motion and preferably also from contact with the steam current. An ample chamber and drain should be provided in steam separators to take care of sudden large quantities of water which may come over by priming.

One of the best precautions against water troubles is 20 degs. to 40 degs. Fahr. of superheat in the steam. Pipe coverings help, but condensation in the pipes is not a great source of danger unless it is allowed to collect. The chief trouble is due to the gradual collection of water in improperly drained pipe, and the carrying over of large clots of water from a boiler which is priming. In general, pipes should not rise vertically in the direction of flow. If it is necessary to do so, a separator should be placed on the horizontal run as near the riser as possible. In exhaust pipes a drain pipe may be used instead of a separator. Pipes should never rise gradually in the direction of flow, as it is impossible to drain them, though they may slant downwards without harm. Particular care has to be exercised with fittings, particularly reduction fittings, to ensure that they do not partially pocket a run of pipe. The fitting pockets, themselves, should be, and generally are, small enough to be immaterial.

Drainage is usually accomplished by pipes ½ in. to 2 in. diameter. 1-in. pipes will care for a good deal of water; and it does not pay to make them too big on account of the cost and radiation. Live steam drainage pipes, which are continuously in use, should be covered; they should also be blown out with live steam every six months. They should be provided with valves wherever necessary, but these valves should be periodically inspected to see that they are hard open wherever they should be. In condensing engines the cylinder drain cocks must be piped to the exhaust pipe. In non-condensing engines they may be piped to the exhaust or to waste; never to the drainage system as the water contains oil. As such pipes carry more or less oil they should be of ample size. Where the steam pipes descend to the engine they should have a small drain pipe, about ½ in., with a valve just above the throttle to take out the condensed water in the pipe before the throttle valve is opened. The same applies to the steam chest drips. With condensing engines the exhaust pipe should drain itself into the condenser, which should be located below the lowest point in the pipe. With non-condensing engines where the exhaust pipe is not self-draining, there should be ¾ in. to 1 in. drips to waste just before the rise, and at the lowest joint of the pipe if there is any other; these drips should not have valves.

Automatic cylinder relief cocks should be drained by 1½-in. to 2½-in. pipes to waste so that the drain may be observed from time to time to detect undue leakage at the cocks. The cylinder steam jackets, and the receiver coils of compound engines, where the latter acts as a reheater should also be drained.

Some arrangements must be made to take the water from the live steam pipes without opening them to low pressures. One or two traps of large capacity, into which all pipes drain, should be connected with high water alarm whistles and hand by-pass valves. The "steam loop," especially as modified in the "Holly System," gives a positive method.

The plain steam loop shown in Fig. 195 draining a separator, operates as follows: The pressure in the separator being supposed to be 95 lbs., and the boiler pressure 100 lbs., water will rise in the "drop leg" 11½ ft. above the boiler water level so as to balance the 5 lbs. pressure difference. Steam enters the "horizontal" from the separator and is condensed by radiation, the water flowing down the drop leg. More steam rushes up the "riser" to fill its place and in doing so entrains water from the separator with it. The whole goes to the "horizontal" where the steam is condensed. Thus the action is continuous. It will be noticed that the condensation in the horizontal being small, the resulting action is correspondingly weak. Also that if the separator becomes filled by a sudden flow of water so that the steam cannot reach the riser, the drainage will stop. This is the vital objection to the simple "loop."

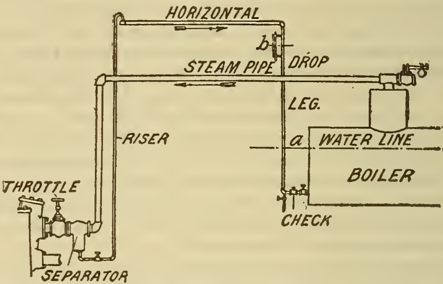


FIG. 195.—PLAIN STEAM LOOP.

Fig. 196 shows the "Steam Loop and Holly Gravity Return System," which is a modified steam loop suitable to practical conditions. *A* shows the receiver, placed below the lowest point to be drained, into which all drainage water flows by gravity, and which is of sufficient capacity to care for sudden large quantities. *I* is preferably but not necessarily the highest point to be drained, not much below boiler pressure, and is likely to have condensation water most of the time. This water flows through the suction T, *L*, which, on the injector principle, helps to draw water through the header *E*-2 from such points as may not be so favorably located as *I*. The water in *A* passes partly through the perforated plate, *H*, and as steam rushes up the riser, *C*, it has to do so through the perforations over the water surface, which materially assists it to entrain water and carry it through the T, *O*, into the discharge chamber, *B*, which is in reality only the top of the drop leg, *D*.

There is no "horizontal" in this system, *i. e.*, no arrangement for the condensation of steam by radiation within the system itself; but instead the pipe *P* takes a small continuous supply of steam to some place where it can be used. Generally the only place where it can be used continuously is the feed water heater, and usually there is but small return for live steam put in there. If the boiler feed pump pumps cold water, a little may generally be fed through the pipe *P*-2 and the "spray" into *B*, which then acts as a condenser and draws the water up higher in *D*, and the steam rapidly up *C*, without experiencing the loss previously mentioned. *A* is equipped with sight gage and loud alarm whistle; *E*-2 and *E* should be furnished with atmospheric discharge valves and pipes for emergency use; the pipes *E*-3 should have valves close to the header. All valves except checks should be gate valves. *P*-1 is a reducing valve, *P*-2, a three-way valve, *F* is a check valve and the starting valve shown is for blowing out air. The boilers should be interconnected by a steam pipe of ample size to equalize their pressure under all conditions. After the system is once properly started it will run indefinitely without attention.

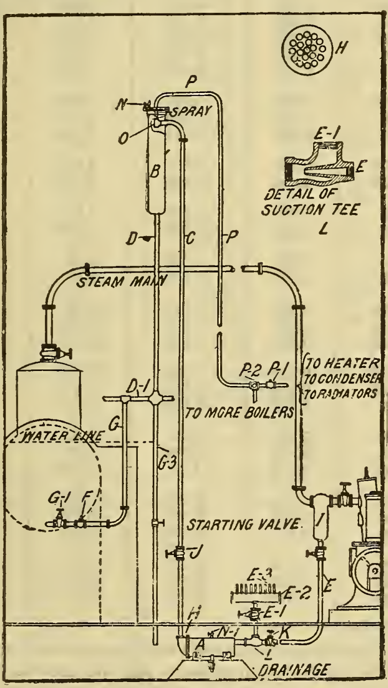


FIG. 196.—HOLLY LOOP.

Coverings.—Steam pipe losses result from friction of the pipe walls, bends and valves, and from radiating heat through the walls of the pipe; but when either of these losses are reduced in the dimensions of the pipe, the other is increased. As the radiation can be decreased largely by insulating the pipe, these losses cannot be equalled for the least profitable investment. There is no inconsiderable loss from conduction through supports and connections in any steam main; an engine indicator connected to it will show the variations of steam pressure for different steam demands, which can be judged from main ammeter readings. If the volume of steam contained in the header is known, the effectiveness of the insulation to

DIMENSIONS OF STANDARD WEIGHT WROUGHT-IRON PIPE.

1¼ and smaller, proved to 300 lbs. per square inch by hydraulic pressure.
1½ and larger, proved to 500 lbs. per square inch by hydraulic pressure.

Nominal Inside Diameter,	Actual Outside Diameter.	Thickness	Actual Inside Diameter.	Weight per Foot.	Threads per Inch.	Taper of Threads
Inches.	Inches.	Inches.	Inches.	Pounds.	Number.	
⅛	0.405	0.068	0.207	0.243	27	$\frac{1}{32}$ in. per inch of screw.
¼	0.54	0.088	0.364	0.242	18	
⅜	0.675	0.091	0.494	0.561	18	
½	0.84	0.109	0.623	0.845	14	
¾	1.05	0.113	0.824	1.126	14	
1	1.315	0.134	1.048	1.670	11½	
1¼	1.66	0.140	1.380	2.258	11½	
1½	1.90	0.145	1.611	2.694	11½	
2	2.375	0.154	2.067	3.600	11½	
2½	2.875	0.204	2.468	5.773	8	
3	3.50	0.217	3.067	7.547	8	
3½	4.00	0.226	3.548	9.055	8	
4	4.50	0.237	4.026	10.66	8	
4½	5.00	0.247	4.508	12.34	8	
5	5.563	0.259	5.045	14.50	8	
6	6.625	0.280	6.065	18.767	8	
7	7.625	0.301	7.023	23.27	8	
8	8.625	0.322	7.982	28.177	8	$\frac{1}{64}$ in. per inch of screw.
9	9.625	0.344	9.001	33.70	8	
10	10.75	0.366	10.019	40.06	8	
11	12.00	0.375	11.25	45.95	8	
12	12.75	0.375	12.000	48.98	8	
13	14.00	0.375	13.25	53.92	8	
14	15.00	0.375	14.25	57.89	8	
——	16.00	0.375	15.25	61.77	8	
——	18.00	0.375	17.25	69.66	——	
——	20.00	0.375	19.25	77.57	——	
——	22.00	0.375	21.25	85.47	——	
——	24.00	0.375	23.25	93.37	——	

radiation can be obtained by closing the connecting valves from the boiler and to the engine, and noting the fall in pressure, and the time that will give for the header its rate of radiation. In order that this test be reliable the valves must be tested for steam tightness. The valve losses from radiation in steam piping are considerable; in a plant with an output of 4200 hp., non-condensing, the losses were as follows: Condensation and conduction, .36 per cent; leakage, .83 per cent; total lbs. of steam per hour lost, 5600 lbs., at an annual cost of production of $1120 per year. Another plant of 2400 indicated horse-power, condensing, showed .83 per cent leakage only.

The condensation loss may be roughly approximated as equal to .55 B. T. U. per hour, per inch external diameter, per foot of bare pipe, per Fahr. degree temperature difference between the pipe and air. The loss per square foot per hour per Fahr. degree temperature difference is about 2.1 B. T. U. Actually, as

DIMENSIONS OF EXTRA STRONG WROUGHT-IRON PIPE.

Nominal Inside Diameter.	Actual Inside Diameter.	Actual Outside Diameter.	Thickness.	Nominal Weight per Foot.
Inches.	Inches.	Inches.	Inches.	Pounds.
1/8	.20	.40	.10	.29
1/4	.29	.54	.12	.54
3/8	.42	.67	.12	.74
1/2	.54	.84	.14	1.09
3/4	.93	1.05	.15	1.53
1	.95	1.31	.18	2.17
1 1/4	1.27	1.66	.19	3.00
1 1/2	1.49	1.90	.20	3.64
2	1.93	2.37	.22	5.02
2 1/2	2.31	2.87	.28	7.67
3	2.89	3.50	.30	10.25
3 1/2	3.35	4.00	.32	12.47
4	3.81	4.50	.34	14.97
4 1/2	4.25	5.00	.35	17.60
5	4.81	5.56	.37	30.54
6	5.75	6.62	.43	28.50
7	6.62	7.62	.50	37.60
8	7.50	8.62	.56	47.85

IRON PIPE SIZES OF SEAMLESS DRAWN BRASS AND COPPER TUBES.

Will thread to fit iron pipe fittings.

Iron Pipe Size.	Inside Diameter.	Outside Diameter.	Length Feet, about.	Approximate Weight per Ft.	
				Brass.	Copper.
1/8	.27	13/32	12	.30	.31
1/4	.36	9/16	12	.43	.45
3/8	.49	11/16	12	.58	.61
1/2	.62	13/16	12	.80	.84
3/4	.82	1 1/16	12	1.17	1.23
1	1.04	1 5/16	12	1.67	1.75
1 1/4	1.38	1 5/8	12	2.42	2.54
1 1/2	1.61	1 7/8	12	2.92	3.07
2	2.06	2 3/8	12	4.17	4.38
2 1/2	2.46	2 7/8	12	5.00	5.25
3	3.06	3 1/2	12	8.00	8.40
3 1/2	3.50	4	12	10.00	10.50
4	4.02	4 1/2	12	12.00	12.00
5	5.04	5.56	8 to 10	15.93	17.30
6	6.06	6.62	6 to 8	20.69	22.38
7	7.02	7.62	Special	26.28	27.77
8	7.98	8.62	Special	29.88	33.69

Pounds of Steam Condensed per Hour per Foot of Covered Pipe, Covering 1 inch thick, having conductivity of ⅛. Temperature of Air 80 degs. Fahr.

External Diam. of Pipe, Inches.	Steam Gage Pressure, Pounds.						
	80	100	120	140	160	180	200
1	.050	.054	.057	.060	.063	.065	.067
2	.101	.108	.114	.120	.125	.130	.134
3	.151	.162	.172	.180	.188	.195	.202
4	.202	.216	.229	.239	.250	.260	.269
5	.252	.269	.286	.299	.312	.325	.34
6	.302	.323	.34	.36	.38	.39	.40
7	.35	.38	.40	.42	.44	.45	.47
8	.40	.43	.46	.48	.50	.52	.54
9	.45	.48	.51	.54	.56	.58	.61
10	.50	.54	.57	.60	.63	.65	.67
12	.60	.65	.69	.72	.75	.78	.81
14	.71	.75	.80	.84	.88	.91	.94
16	.81	.86	.91	.96	1.00	1.04	1.08
18	.91	.97	1.03	1.08	1.13	1.17	1.21
20	1.01	1.08	1.14	1.20	1.25	1.30	1.34
22	1.11	1.19	1.26	1.32	1.38	1.43	1.48
24	1.21	1.29	1.37	1.44	1.50	1.56	1.61

ECONOMY DUE TO SUPERHEATED STEAM.

	Steam Saturated 2nd Test.	Steam First Test.	Superheated Third Test.
Amount of superheat	0.	118.3°F.	126.9°F.
Boiler pressure, gage	95.7	99.	94.
Temperature of superheated steam	334.8°F.	455.3°F.	460.4°F.
Indicated hp.	475.	491.	502.3
Lbs. of steam per lb. of coal	6.276	6.024	6.
Lbs. of steam per 1 hp-hour	19.75	15.63	15.61
Lbs. of coal per 1 hp-hour	3.147	2.593	2.513
Per cent saving in steam due to superheating	....	20.9	20.9
" " " " coal " " "	....	17.6	20.1

the pipe temperature increases, the loss increases a little faster. Another method of comparing the value of different coverings is to have a cone of heat-insulating material fitting over the pipe surface to be tested, and with the same steam temperature for the different samples measure the rate of rise of temperature in the air space inside the cone. The loss from covered pipes depends on the thickness, kind and quality of the covering and somewhat on the extent to which it is compressed.

Coverings in common use are carbonate of magnesia and asbestos, the latter being sometimes combined with other materials such as hair and woolen felt. A little asbestos is usually put in magnesia coverings to bind the material. So called "Magnesia Covering" is usually 1 in. thick up to 12-in. pipe, over which it runs 1¼ ins. to 1½ ins. in thickness. This covering contains practically no magnesia. The loss for two samples having a small percentage of good asbestos was .65 and .87 B. T. U. per sq. ft. per hour per Fahr. degree temperature difference, *i. e.*, the loss was 31 per cent to 41½ per cent of uncovered pipe. The latter value was for the denser sample.

Pure asbestos generally gives the same or a trifle greater loss than bare pipe. "Air Cell Asbestos" about equals "Magnesia Covering." The following tests of commercial coverings were made by Geo. M. Brill and reported in Trans. A. S. M. E., Vol. XVI., page 827. A length of 60 ft. of 8-in. steam pipe was used in the tests, and the heat loss was determined by the condensation. The steam pressure was from 109 lbs. to 117 lbs. at the gage, and the temperature of the air from 58 degs. to 81 degs. Fahr. The difference between the temperature of steam and air ranged from 263 degs. to 286 degs., averaging 272 degs.

REPORT OF TESTS ON STEAM PIPE COVERINGS.
(G. M. Brill.)

Kind of Covering.	Thickness of Covering. Inches.	Lbs. Steam condensed per sq. ft. per hour.	B. T. U. per sq. ft. per minute.	B. T. U. per sq. ft. per hour per degree of average difference of temperature.	Saving due to covering, lbs. steam per hour per sq. ft.	Ratio of heat lost, bare to covered pipe, per cent.	H. P. lost per 100 sq. ft. of pipe (30 lbs. per hour = 1 H. P.)
Bare pipe	....	.846	12.27	2.706	......	100.	2.819
Magnesia	1.25	.120	1.74	.384	.726	14.2	.400
Rock wool	1.60	.080	1.16	.256	.766	9.5	.267
Mineral wool	1.30	.089	1.29	.285	.757	10.5	.297
Fire-felt	1.30	.157	2.28	.502	.689	18.6	.523
Manville sectional	1.70	.109	1.59	.350	.737	12.9	.564
Manv. sect. & hair felt	2.40	.066	0.96	.212	.780	7.8	.221
Manville wool-cement	2.20	.108	1.56	.345	.738	12.7	.359
Champ. mineral wool.	1.44	.099	1.44	.317	.747	11.7	.330
Hair-felt	.82	.132	1.91	.422	.714	15.6	.439
Riley cement	.75	.298	4.32	.953	.548	35.2	.993
Fossil-meal	.75	.275	3.99	.879	.571	32.5	.916

Exhaust Piping.—In long exhaust pipes, radiation is very objectionable, for the steam becomes ladened with the condensed moisture and the weight opposed to the engine exhaust is greater. Every pound of pressure lost in this way cuts off just so much from the bottom of the indicator card and calls for a higher steam supply to do the same work. It is therefore imperative that this loss should be kept down as far as possible in exhaust pipes. In condensing engines the exhaust pipe may generally be made comparatively short, though the M. E. P. of condensing engines is rather lower than in the non-condensing type. The loss should be a function of the length of pipe, and in either type of engine should not exceed 1 lb. per 100 ft. actual run plus ¼ lb. In exhausts over buildings the weight of the steam column must be added to the back pressure, and the size of exhaust pipes will show economy for larger sizes than the formula for live steam pipe indicates. An exhaust connected to a vacuum must be air tight in order that the condenser will not fail at full load.

Exhaust Heads should be placed on atmospheric exhaust pipes where the noise or water and oil of exhaust are objectionable. Cases have occurred where the exhaust pipe opening over the building roof and only one or two engines running, the roof and floors below have been set into periodic vibrations by the varying air pressure over the roof. The exhaust head is in principle a good deal

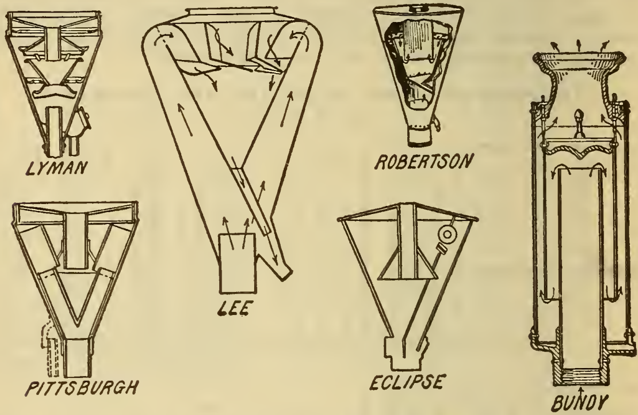


Fig. 197.—Types of exhaust heads.

like a separator, in so far as the separation of fluid is concerned; the reduction of noise is accomplished by the reduced velocity of the steam from the end of the cone and also by the steam chamber action similar to the air chamber principle in water pumps. Fig. 197 shows several types of modern exhaust heads.

EXHAUST-STEAM CONDENSERS.

The Jet Condenser.—This consists of a chamber into which the exhaust steam and a jet of cool water are conveyed, the exhaust steam being condensed by actual mixing with the latter. The volume of this condensing chamber is ordinarily from one-third to one-half that of the cylinder of the engine.

The water of condensation acting directly upon the steam will make a given lowering of temperature of the exhaust steam with less weight of water and less bulk and weight of condenser. To condense steam requires from twenty to thirty times the weight of water in cool seasons or climates, and from thirty to thirty-five times with warm water, as shown by the table on opposite page.

Where the condensed steam is to be pumped back into the boiler, the injection water goes with it; therefore it must be water that is not objectionable for use in boilers.

The total heat contained in 1 lb. of steam as it leaves the low pressure cylinder of a condensing engine, is about 1133 B. T. U. above that contained in

COMPARATIVE WEIGHTS OF INJECTION WATER AND STEAM.

Temperature of Hot Well.	Corresponding Back-Press. in Cylinder.	Temp. of Injection Water, Fahr.					
		40	50	60	70	80	90
Degs. Fahr.	Lbs. per sq. inch.	Ratio of weight of injection water to weight of steam.					
100	0.94	17.8	21.4	26.8	35.7	53.5	107.0
110	1.27	15.1	17.7	21.2	26.5	35.3	53.0
120	1.68	13.1	15.0	17.5	21.0	26.3	35.0
130	2.21	11.6	13.0	14.9	17.3	20.8	26.0
140	2.88	10.3	11.4	12.9	14.7	17.2	20.6

1 lb. of water at 32 degs. Fahr. and the weight of water required to condense this steam is $\frac{1138 + 32 + T}{T - t} = \frac{1170 - T}{T - t}$, where T is the temperature of the hot well, and t the temperature of the injection water, T is usually from 100 degs. to 120 degs. Fahr.

The area of the injection pipe is approximately $\frac{W}{130\sqrt{h}}$ where W is the weight of injection water required per minute in lbs. and h the head of water in feet.

The Surface Condenser.—This type differs from the foregoing in the fact that the exhaust steam is not mixed or brought in actual contact with the water

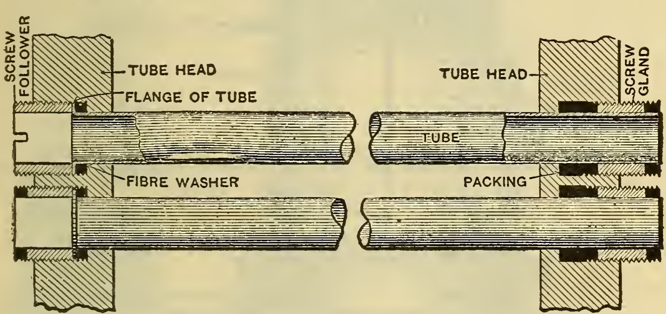


FIG. 198.—METHOD OF SECURING TUBES IN SURFACE CONDENSERS.

which condenses it. In the surface condenser the steam is separated from the cool water by metallic partitions or tubes, the ordinary arrangement being to pass the cool water through brass tubes around which the steam is caused to circulate, or vice versa. The condensing surface required is usually from 1½ to 3 square feet per indicated horse-power.

The surface condenser, while more heavy and bulky to handle for cooling a given weight of steam discharged as exhaust, can be used with any kind of water. The condensed steam can be used again in the boiler, but the effect of distilled water is to increase the corrosion in the boiler, and from 10 per cent to 12 per cent of its weight of fresh water has to be added in order to reduce this effect.

Oil must be separated from the steam, and oil separators should be used in the exhaust steam main before it enters the condenser. This method is useful when the only available water contains solid matter, salts or acids which would be

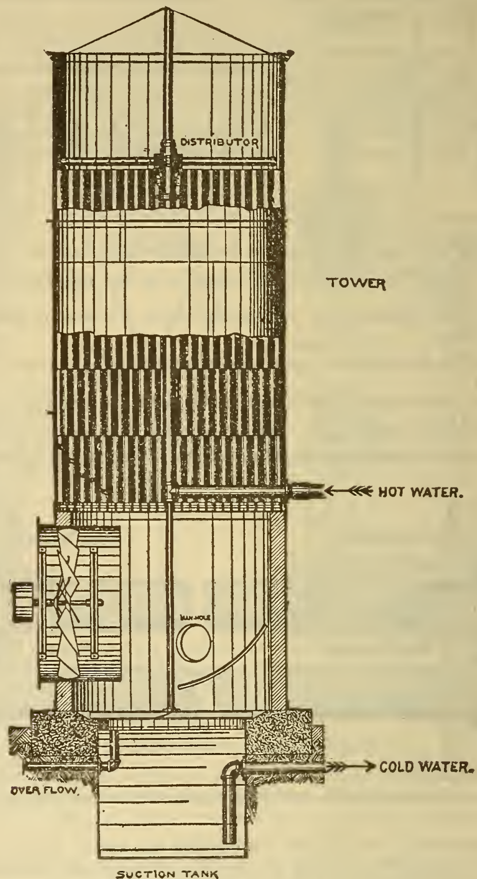


FIG. 199.—SELF-COOLING CONDENSER.

injurious to the boilers. The same water is used over again and so the steam circuit is practically a closed one.

The brass tubes of the condenser are solid drawn, and are generally tinned outside and inside. They vary in diameter from ½ in. to 1 in., but generally are ¾ in. outside diameter. Such tubes are about .048 in. in thickness.

The tubes are generally secured to the tube plates by screwed glands and stuffing boxes, packed with cotton cord or a ring of thick tapes, as shown in Fig. 198. They are placed zigzag, and their pitch measured from center to center, may be from 1.5 to 1.7 their diameter.

The thickness of tube plates equals the diameter of the tubes in inches, plus ¼ in.

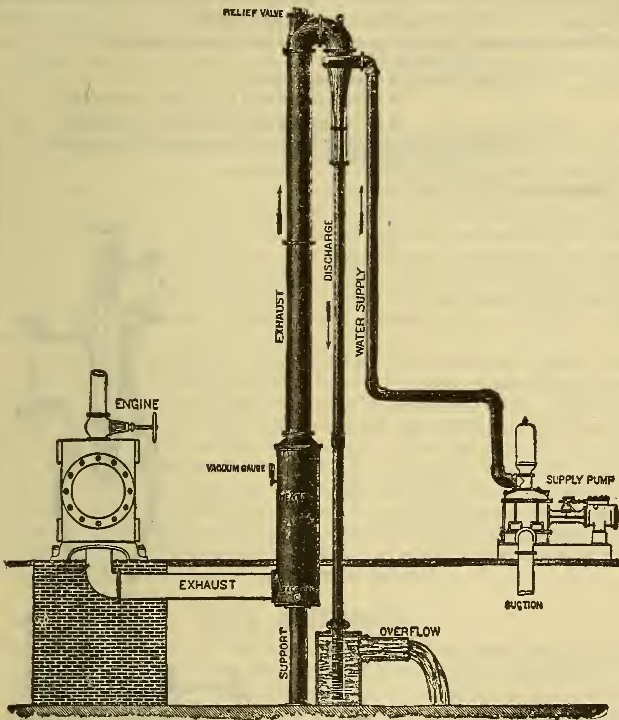


FIG. 200.—SYPHON OR INJECTOR CONDENSER.

In the surface condensers of modern triple expansion marine engines the amount of cooling surface is from 1.1 sq. ft. to 1.5 sq. ft. per indicated horsepower. Prof. Whitham's rule for the amount of cooling surface is:

Where S equals cooling surface in sq. ft.
W " weight of steam to be condensed per hour in lbs.
T " temperature of steam to be condensed.
t " mean temperature of circulating water which is the arithmetical mean of initial and final temps.
L " latent heat of steam of temperature T.

Then $S = \frac{WL}{180\,(T - t)}$

If T equals 135 degs. and t about 75 degs., then $S = \frac{17\,W}{180}$

The amount of cooling water required is determined in the same way as for jet condensers, except that it must be noted that the temperature of the cooling water as it leaves the condenser is not the same as that of the condensed steam. The formula for determining this weight is as follows:

Where H = total heat in 1 lb. of steam above that contained in 1 lb. of water at 32°.

T = temperature of condensed steam.

t = " of circulating water as it enters condenser.

t_1 = " of circulating water as it leaves condenser.

W = weight of circulating water (in lbs.) required for each lb. of steam condensed.

Then $W = \frac{H + 32 - T}{t_1 - t}$

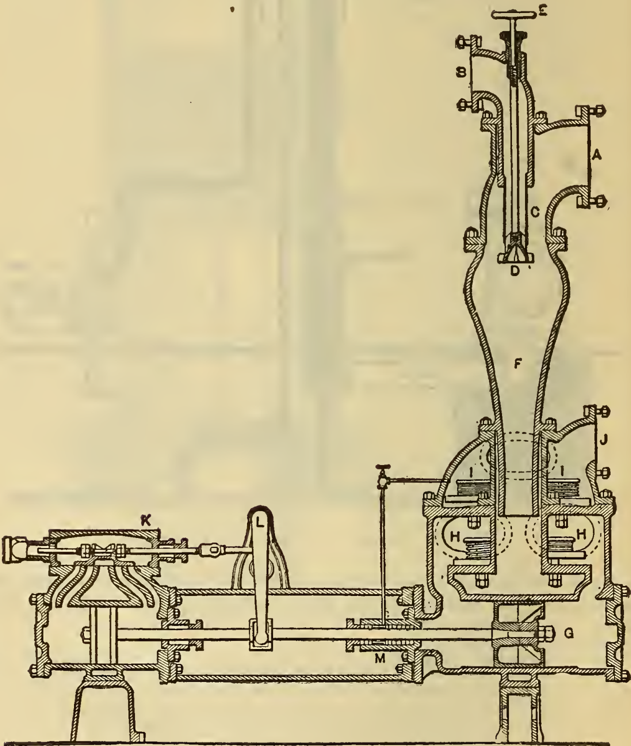


FIG. 201.—INJECTOR CONDENSER WITH PUMP.

Self-Cooling Condenser.—This type, shown in Fig. 199, consists of two parts: the condenser in which the exhaust steam of the main engine, or engines, is condensed, and the tower in which the heated discharge water from the condenser is cooled to proper temperature, to be used again in the condenser for the further condensation of the exhaust steam. As this process is carried on continuously, only a very small supply of circulating water is required.

The heated water falling through the tower is cooled by three processes: first, radiation from the side of the tower; second, the contact of cool air; and third, evaporation. The cooled water falls from the grating to the subsiding tank at the bottom, and is from there drawn by the condenser to be again employed in condensation. The current of air is passed through the tower by a circulating fan.

The Siphon or Injector Condenser.—This condenser is shown in Fig. 200. The exhaust steam receiving a downward direction in passing through the goose neck at the top of the apparatus passes through an inner cone, surrounded by an annular cone of water. The steam is condensed in this conical space, and falls with the injection, whose velocity is so graded by the cross section of the condenser that air in the injection is entrained and has no opportunity to remain in the space where the vacuum is. The small vacuum cone being continually filled and emptied prevents the trouble from air. There is no air pump, but the injection pump is required as before. Where a height of water of 9 ft. to 12 ft. above the hot well is available a natural flow of water can be used instead of the supply pump.

The Injector Condenser with Pump.—There are many places where the height required for the long leg or siphon of the barometric condenser is inconvenient. This has given rise to a design of condenser, Fig. 201, in which the small bulk of the injector and its efficient action are combined with a pump to maintain the vacuum by continually drawing off the water and the air. The exhaust steam enters through the inlet *B*, whieh is controlled by an inner pipe *C*, that carries a deflecting nozzle *D*; this throws the injection in a finely divided state into the annular exhaust steam passage *F*, and the air pump below continuously draws off the water mixed with air, to which a higher velocity is given by reducing the cross-section, so that the bubbles of air once caught in the water have no chance of rising into the vacuum space below *D*.

GAS ENGINES.

These are used successfully in several railway plants, and, where the gas is used directly from the holder without distribution expense, they show a high thermal efficiency, and their cost of operation per kw-hour compares favorably with a steam plant. A multi-cylinder engine is necessary in order to give constant voltage, the flywheel has to be large, and the capacity of the generators should be considerably under the capacity of the gas engine. In gas engines the consumption of coal gas may be taken at 20 cu. ft. per 1 hp-hour, 24 cu. ft. per brake hp-hour. With engines of 100 hp the equivalent coal consumption was 1.1 lbs. of coal per hp-hour, and the mechanical efficiency, 85 per cent; this improves with larger engines.

WATER POWER.

The value of water power for railway work depends upon the supply being ample at all times and seasons to operate the whole load. Small water powers, as a variable supplementary, do not often show an economy sufficient to encourage their development, where the location is not adapted to directly supply the railway system. The water flow should be measured at that season of the year, which has the lowest flow for the water shed drained by the stream. In order to determine the flow of water in an open stream, where the channel has a fairly uniform depth and width, twelve to twenty equidistant measurements across the channel should be taken from the bottom of the channel to the surface of the water; their sum divided by their number will give the average depth.

The velocity of the flow of water can be measured by the time required for a float to pass between two parts located 100 ft. apart. As the surface of a stream at the center moves approximately 83 per cent faster than the sides and bottom, certain allowance has to be made. The cross section in feet multiplied by the

RESULTS OF TESTS ON A "CYLINDER GATE" VICTOR TURBINE.

SIZE OF WHEEL.	Head in feet.	Revolutions of Wheel per minute.	Cubic Feet Water per minute.	Horse Power developed by Wheel.	Percentage Useful Effect.
30-inch Full Gate	17.51	168	4440	119.56	81.35
7/8 "	17.82	163	3892	104.93	80.03
3/4 "	17.95	163	3392	88.21	76.06
5/8 "	18.10	155	2893	70.97	71.28
1/2 "	18.20	159	2265	51.42	63.46
36-inch Full Gate	16.78	135	6106	158.18	81.80
7/8 "	17.14	135	5422	141.58	80.71
3/4 " ..	17.35	140	4708	118.22	76.08
5/8 "	17.05	129	3982	91.62	71.50
1/2 "	17.48	134	3202	66.87	63.30
39-inch Full Gate	14.66	116	6873	152.66	80.37
7/8 "	14.53	118	5920	129.41	79.80
3/4 "	16.84	125	5517	135.56	77.40
5/8 "	17.06	123	4695	108.22	71.67
1/2 "	17.39	124	3856	81.00	64.07
48-inch Full Gate	13.23	91	10072	201.71	80.11
7/8 "	14.36	89	9042	192.41	78.42
3/4 "	14.75	89	7869	165.23	75.34
5/8 "	14.87	85	6744	132.76	70.06
1/2 "	15.28	87	5526	100.66	63.09

velocity in feet per minute, will be the discharge in cubic feet per minute. By taking levels to obtain the height of fall that can be secured, and multiplying this height in feet by the cubic feet per minute, multiplied by 62.36 lbs. (the weight of 1 cu. ft. of water at 60 degs. F.) and dividing by 33,000 the gross horse-power of the water power can be obtained.

In estimating the recoverable water power, allowances have to be made for the turbines of from 75 per cent to 85 per cent efficiency at full gate. There is also loss of head due to weirs, and the necessary drop to produce flow in the flumes and raceways, and in addition the suction effect on the turbines in a penstock is sometimes reduced by the presence of air decreasing the draft tube effect. All these losses combine to reduce the possible recovery of power and should be given ample allowances in estimating water powers for railway work.

Turbines, etc.—The power obtained by turbine wheels is due to the impact of the water against the curved buckets attached to the rotating shaft. The form and angle of these buckets and their spacing varies with the different types of turbines.

For heads above 100 ft., the Pelton wheel can be used effectively, and the regulation by a deflected nozzle responds much more readily to the load changes than in the case of turbines, where the regulator opens and closes the gate and affects the flow of water through the turbine. Automatic regulators, however, have been made for turbines, which give very satisfactory results for railway work, if close attention is given to their adjustment.

Overshot wheels, due to their large inertia value, show some points in favor of their use in railway work for small plants, but their efficiency is so poor as to prohibit their use except where there is an abundant surplus of water.

The table given herewith shows the results of tests on a Victor Turbine, made by the Stilwell-Bierce & Smith-Vaile Co., carried out at the testing flume of the Holyoke Water Power Co., Holyoke, Mass.

THE RAILWAY GENERATOR.

The generator is the most economical transformer of energy in the station, and consists essentially, in its simplest form, of two parts: the armature, which in revolving induces a potential in the copper conductors wound on its surface, when these conductors pass through or across a magnetic field; and the field magnet, whose function is to produce a flux or flow of magnetic lines through the revolving armature. The successful design of a generator is the happy compromise of many conflicting losses, and it is not within the scope of this hand book to discuss these complex relations, which can be found fully treated in "Dynamo Electric Machinery" by Sylvanus P. Thompson, and similar books.

Efficiency.—As all losses in the generator appear in the form of heat, the temperature is the criterion accepted as a gage of efficiency. The field magnets require a certain amount of energy developed by the armature; this varies from .75 per cent for generators above 500 kw to 1.8 per cent for 150 kw generators. The temperature of the field should not rise more than 30 degs. Cent. above the air, the temperature of the air being 20 degs. Cent. by the thermometer; or show by resistance measurements a resistance greater than that corresponding to 45 degs. Cent.; 1 watt per square inch of external surface of field gives a rise approximately of 62 degs. cent. by the thermometer. For field surfaces the approximate requirement is 15 sq. ins. per kw output.

The Field.—A railway generator, is usually compound-wound. In this type there are two separate systems of field coils, one is the shunt, which is connected across the full potential, and in series with this circuit there is a rheostat for varying the current through the shunt coils, in this way changing the magnetic field through which the armature rotates. The resistance of this rheostat should be sufficient to bring the potential of the armature, run on open circuit at full speed, 20 per cent below the normal bus voltage; this requires in different types of generators a rheostat resistance of from ½ to 2 times the field resistance. The other, the series fields, increases the field intensity due to the current from the generator passing around the field, and tends to maintain the potential of the generator. The generator is over compounded for increasing loads so that the degree of compounding required depends on the drop of potential on the distribution system which the generator supplies. Twenty per cent over compounding is the usual amount employed for railway work, but the compounding coils can be shunted by a resistance to reduce this effect to any desired per cent of compounding. This is the usual way that manufacturers adjust machines for compounding requirements under 20 per cent. There is a condition arising in railway plants extending over considerable territory, where the line drops are considerable but not sufficient to warrant a booster, which can be met by having the generator wound to give two percentages of compounding. This can be done by opening the shunt coil around the series compounding, and separating the outlying feeders from the short feeders on the switchboard. It also requires two equalizing busses, and the generator can then be operated for a large percentage of over-compounding to make up for the line drop and operated independently on the long feeders, which will produce better potential delivery at their ends.

The watts lost in each field should be equal to the product of the drop across each field and the current flowing through it. If the fields vary, it is due to short-circuited turns on the field or poor connections; the former is usually found in overheated shunt fields, and the latter in the series field connections.

The Armature.—This is composed of discs of thin sheet iron or steel assembled on the shaft. The modern armature has slots on the periphery of the armature body, through which the windings pass. The current density varies from 300 circ. mils per ampere to 800 circ. mils per ampere in the ventilated types; 800 circ. mils per ampere to 1100 circ. mils per ampere in the unventilated types.

The ventilation in the armature is effected by separating the different groups of discs by an open spider, which allows the air to pass from the interior of the armature body to the exterior, it being thrown out by centrifugal force due to the rotation of the armature. The energy lost in the armature is due to the resistance of the armature windings, the internal drop varying from 7 per cent for 50-kw to 2 per cent for 2000-kw machines.

The other loss in the armature is due to hysteresis and eddy currents set up in its iron which acts as a conductor cutting the magnetic field. These losses aggregate from 6 per cent for a 50-kw generator to 2.6 per cent for a 1200-kw generator.

The radiating surface per kw output in armatures should be from 20 sq. ins. to 18 sq. ins. in a 1200-kw generator. The peripheral speed varies from 2000 ft. to 3200 ft. per minute. The insulation resistance should be at least from 1 to 3 megohms, cold, and 1 megohm to 750,000 ohms, hot, and should be subjected to an alternating pressure of 2500 volts for 5 minutes without break down. The latter test is much more severe when made while the armature is hot.

The Commutator.—This is built up of a number of segments of copper insulated from each other and from their mechanical support by mica. The purpose of the commutator is to rectify the alternating currents which are induced in the armature coil when passing from one pole face to the next. The conditions of the commutator require that as few turns as possible be connected to the brush at the same instant, for, when in this position, the coils are short-circuited and a local current circulates through them and the brush bridging the coils. The electromotive force, due to the flux distribution in the field and the number of bars connected to the coils between pole centers, limits the possible local current that can circulate in the coils under the commutator.

The sparking, which the opening of this circuit produces, is shown in the character of wear on the commutator. A dark bronze uniform color of the commutator is the desired surface. Sparking produces bright metallic lines around the commutator, or pits the commutator next the mica segment towards the brush in the direction of rotation. The terms of undue and excessive sparking, as applied to commutation in the generator, are relative and the proper commutation should be defined by the character of the surface and wear on the commutator. The radiating surface on a commutator varies between 5½ to 3¾ sq. ins. per kw output.

Brushes and Brush-Holders.—The brushes for railway work are usually of carbon. The curvature of brush should be fitted to the commutator so as to give uniform wear to the segments and mica insulation. It should be hard enough to produce a gloss without cutting, and not soft enough to give a black film on the commutator. The brushes must be of uniform density and should show a bright contact surface which has the appearance of graphite.

The loss in potential between the commutator bar and the brush should not exceed 1.4 volts at full load, and the current density on the contact surface should not exceed 40 amps. per square inch. In early generators there was from ¾ volt to 1 volt loss between the carbon brush and its holder; this has been reduced by connecting a flexible lead between the brush and its holder, looping out this contact resistance and reducing the drop to ¼ of a volt or less. The brush-holder should be sufficiently flexible to yield to any inequality in the rotating commutator. and yet produce a pressure of 1.2 to 1.7 lbs. per square inch of contact surface. The movement of the brush-holder to accommodate wear should be such as to keep the brush parallel to the wearing arc. The best position of the brushes relative to the commutator is generally marked on the rocker, or its position can be found on loading the generator, and finding the point of least sparking for the normal load.

For polishing a commutator use only sandpaper. Have a concave wooden segment covering about ¼ of the commutator, between the brushes, to which is secured the sandpaper, and which is pressed against the commutator surface with the armature revolving at moderate speed.

Bearings.—These are about 3.8 times their diameter in length for 100-kw to 300-kw, and from 3.2 to 3 above 300-kw direct-connected generators. The engine manufacturer supplies the shaft and engine bearing, and the dynamo manufacturer supplies the outboard bearing, when one is required. The armature is built up on a keyed sleeve which is forced on the engine shaft. The engine manufacturer usually supplies the dynamo manufacturer with a gage from which the armature sleeve is bored, so that it will take the desired pressure in tons to force the armature home on the shaft.

The bearings are always self-oiling either by rings or a chain, revolving over the shaft, the lower extremity moving in the oil well. Where the oil circulating system is used, oil is kept flowing into the oil well and drained from an overflow pipe, keeping the oil at a constant level. This has the additional effect of cooling the bearings. As the air, passing through the armature, draws any oil spray thrown by the reciprocating parts, the armature should be screened from it, for manufacturers justly demand, that in order to maintain their guarantees, the armature must be free from oil. Oil carbonizes at the temperatures attained, and acts as an adhering surface to which carbon dust from the brushes can cling. thus tending to break down the insulation of the armature windings.

The armature shaft bearings should be scraped to a fit and be adjustable for wear, to maintain the alignment of the armature in its field. In belted machines, above 250 kw, it is considered good practice to provide an outboard bearing to carry the belt strains. In direct-connected generators the bearing friction is about 0.32 per cent of delivered horse-power, and in belted, from .62 per cent to 1.25 per cent of delivered horse-power, depending upon the size and bearing design.

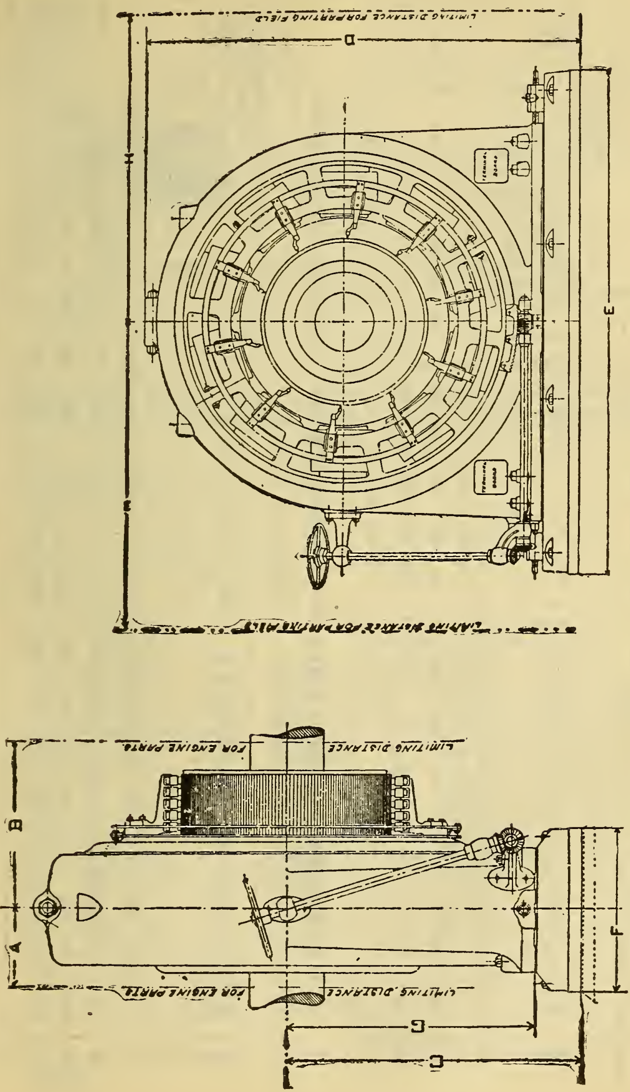
SIZES AND APPROXIMATE DIMENSIONS OF WESTINGHOUSE STANDARD ENGINE-TYPE RAILWAY GENERATORS.

K. W.	Amperes at 550 Volts.	Poles	R. P. M.	Approx. Net Weight. Lbs.	A Ins.	B Ins.	C Ins.	D Ins.	E Ins.	F Ins.	G Ins.	H Ins.
150	270	8	200-225	18,700	15½	27½	46¼	82⅞	120	36	37¼	84
150	270	8	170-185	24,000	15½	30	51¼	94¼	120	36	42¼	96
200	364	8	200-220	24,400	13	30	51¼	94¼	120	36	42¼	96
250	455	8	150-170	30,600	17	30½	54¾	101	120	36	45¾	102
250	455	8	120-125	43,200	16	36	62½	114½	144	39	52½	108
250	455	10	90-100	50,000	18	32	67¼	124¼	144	39	57	114
300	546	8	145-160	43,400	17	39	62½	114½	144	39	52½	108
325	590	8	90	61,500	19	38	71½	131⅝	144	39	60¾	120
400	725	10	90-100	78,000	22	39	73¾	138⅜	176	47½	63½	126
500	910	8	150	62,000	18	38	71½	131⅝	144	39	60¾	120
500	910	10	90-100	100,000	21	39	80¼	152¾	171	42	70	144
800	1455	10	80-90	135,000	24	48	88¼	166¾	204	52½	76	144
1050	1910	12	80	147,000	22	50	95¾	180½	252	53½	83	168
1200	2180	12	75-80	185,000	22	52	100¾	191⅜	252	53½	88½	192
1500	2730	14	75-80	200,000	23	54	109¾	209⅝	276	55	97½	204

NOTE.—In the above table the machines which are indicated as having either of two speeds may be operated at 550 volts at either speed, or at 575 volts at the higher speed.

SIZES AND APPROXIMATE DIMENSIONS OF SPECIAL ENGINE-TYPE RAILWAY GENERATORS.

K. W.	Amperes.	Volts.	Poles.	R. P. M.	Approx. Weight. Lbs.	A Ins.	B Ins.	C Ins.	D Ins.	E Ins.	F Ins.	G Ins.	H Ins.
800	1230	650	10	80	135,000	24	46	88¼	166¾	204	52½	76	144
1050	1830	575	12	80	147,000	22	50	95¾	180½	252	53½	83	168
1500	2300	650	14	80	200.000	19	47¾	109¾	209⅝	276	55	97½	204
1800	4400	410	20	75	247,900	24	56	129¼	244⅝	312	62	111	204
2700	4700	575	24	75	312,500	24	58	144$\frac{3}{16}$	277$\frac{9}{16}$	336	62	125⅞	216



FIGS. 202 AND 203.—SIDE AND FRONT VIEW OF WESTINGHOUSE DIRECT-CONNECTED GENERATORS.

WESTINGHOUSE 6-POLE, 3-BEARING DIRECT-CURRENT RAILWAY GENERATORS.

K W.	Amperes.	R. P. M.	A	B	C	E	F	F	M	N	P	R	S	T	Pulley. Diam.	Pulley. Face	Pulley. Length of Hub.	Key-Way in Shaft. Width.	Key-Way in Shaft. Depth.	Weight Net Lbs.
			Ft. Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ft. Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
250	455	450	12 $4\frac{1}{4}$	$54\frac{5}{8}$	$93\frac{5}{8}$	$6\frac{1}{2}$	$50\frac{1}{2}$	39	88	46	98	$49\frac{1}{4}$	$88\frac{1}{4}$	11 $5\frac{1}{2}$	38	42	32	$1\frac{9}{16}$	$\frac{9}{16}$	24,750
500	910	320	15 $8\frac{3}{4}$	$65\frac{1}{2}$	$123\frac{1}{4}$	$8\frac{1}{2}$	$67\frac{1}{4}$	54	$119\frac{1}{3}$	61	$123\frac{1}{2}$	61	$118\frac{3}{4}$	14 $11\frac{3}{4}$	60	64	42	$2\frac{1}{8}$	$\frac{5}{8}$	46,000

WESTINGHOUSE 6-POLE, 2-BEARING DIRECT-CURRENT RAILWAY GENERATORS.

K W.	Amperes.	R. P. M.	A	B	C	E	F	F	M	N	P	Q	R	S	T	Pulley. Diam.	Pulley. Face.	Pulley. Length of Hub.	Key-Way in Shaft. Width.	Key-Way in Shaft. Depth.	Weight Net Lbs.
		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
100	182	650	$85\frac{3}{16}$	$43\frac{7}{8}$	$41\frac{5}{16}$	$3\frac{7}{8}$	$35\frac{7}{9}$	24	$61\frac{1}{8}$	30	61	67	$34\frac{5}{8}$	$23\frac{7}{8}$	$58\frac{1}{2}$	28	18	10	$\frac{7}{8}$	$\frac{3}{8}$	9,400
150	273	550	$96\frac{1}{4}$	$48\frac{1}{8}$	$48\frac{1}{3}$	$4\frac{3}{4}$	39	29	$70\frac{1}{4}$	35	$75\frac{1}{2}$	81	$38\frac{7}{8}$	$25\frac{3}{8}$	$64\frac{1}{4}$	34	26	16	1	$\frac{3}{8}$	14,000
200	364	510	ft. in. 9 2	$50\frac{3}{4}$	$59\frac{1}{4}$	$5\frac{7}{8}$	$47\frac{1}{2}$	$32\frac{1}{2}$	$77\frac{3}{4}$	$38\frac{1}{2}$	82	$87\frac{1}{2}$	$43\frac{7}{8}$	$29\frac{1}{8}$	73	35	33	20	$1\frac{9}{16}$	$\frac{9}{16}$	19,730

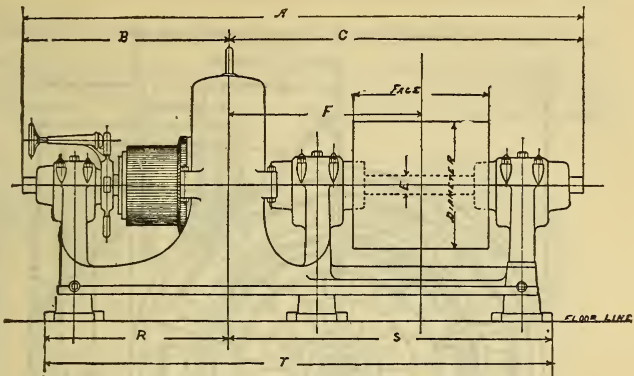
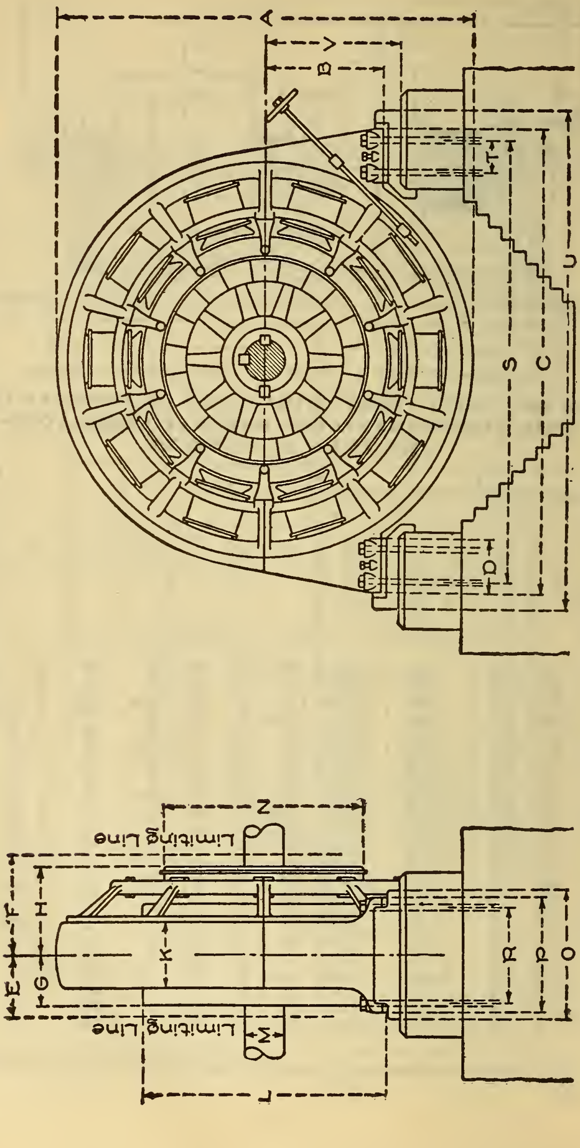


FIG. 204.—SIDE VIEW OF WESTINGHOUSE BELTED GENERATOR.

SIZES AND APPROXIMATE DIMENSIONS OF GENERAL ELECTRIC DIRECT-CONNECTED RAILWAY GENERATORS. MP, FORM H, 575 VOLTS.

CLASSIFICATION.			APPROX. WEIGHT.								
Poles	Kw.	Speed	Armature and Commutator	Generator Complete	A	B	C	K	L	M	N
6	100	275	4,000	15,000	80½	20	95	18	36	5½-	24½
6	150	200	6,400	29,000	99	23	114	25	45	9 -	32
6	200	200	9,000	39,000	116	26	133	26½	59¼	9 -10½	44
6	200	150	10,500	50,000	118½	26	136	29	59¼	9 -11½	44
8	300	150	17,000	55,000	125	32	141	27	68	11½-14	49
8	300	120	19,000	65,000	128	38	145	30½	68	12 -15	49
8	300	100	20,500	75,000	130	38	146	33	68	14 -16	49
8	400	150	21,000	68,000	132	41	148	30	72	14 -16	49
8	400	120	22,000	79,000	135	41	150	32½	72	15 -18	49
8	400	100	24,000	90,000	137½	41	152	34½	72	15 -18	49
10	500	120	25,000	81,000	144½	44	154	30	84	16 -18	60
10	500	100	29,000	96,000	160	47	178	30½	96	16 -18	84
10	500	90	36,000	110,000	161	47	180	33	96	16 -18	84
10	500	80	37,000	118,000	162	47	180	34½	96	16 -18	84
12	650	90	41,000	117,000	173	47	188	32	108	18 -20	84
12	800	120	42,000	113,000	173	47	188	31	108	19 -22	84
14	800	100	47,000	118,000	186	53	200	28	120	19 -22	84
14	800	80	50,000	135,000	187	53	201	32	120	19 -22	84
16	1,000	80	58,000	150,000	187	47	209	32	120	22 -25	100
18	1,200	80	66,000	156,000	195½	47	221	30½	130	24 -27	100
22	1,600	75	74,000	180,000	230	63	245	24	164	24 -27	120
28	2,000	75	87,000	188,000	285	48	312	26	204	27 -30	150
28	2,400	75	100,000	225,000	320	48	364	26	232	27 -30	180

These dimensions should only be used for approximate size and are subject to change.



FIGS. 205 AND 206.—SIDE AND FRONT VIEWS OF GENERAL ELECTRIC DIRECT-CONNECTED GENERATOR.

ROTARY CONVERTERS AND DOUBLE-CURRENT GENERATORS.

Direct-current dynamos generate alternating current in their armature windings which are rectified by the commutator and delivered to the external circuit as direct current. If collector rings are connected to the windings at suitable

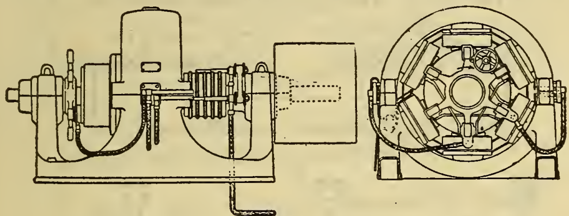
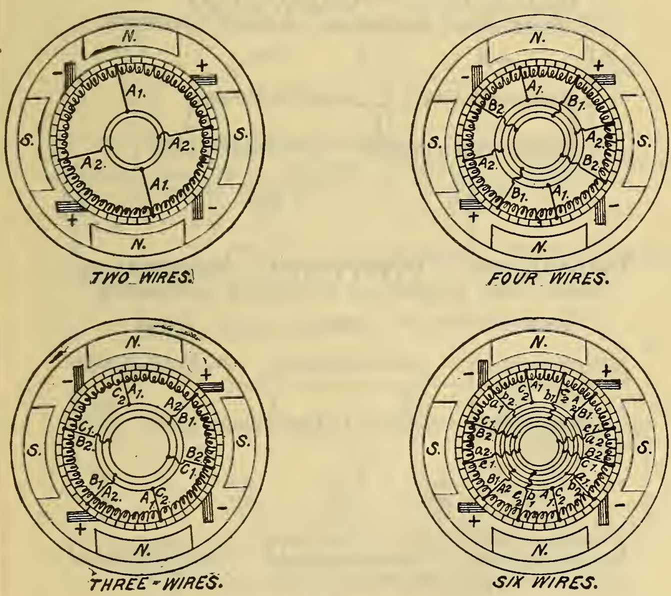
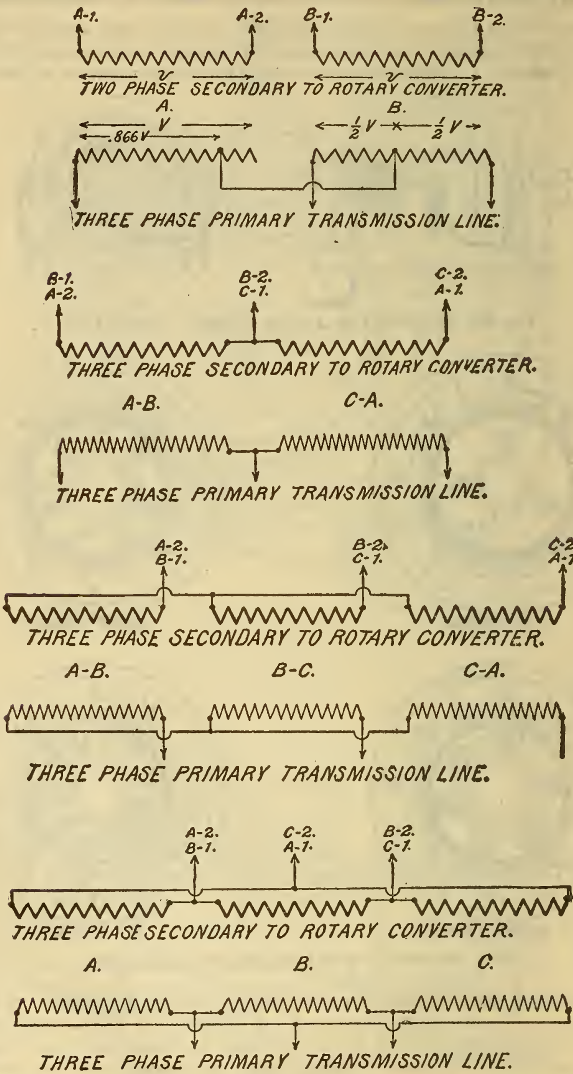


FIG. 207.—ALTERNATING DIRECT CURRENT GENERATOR.

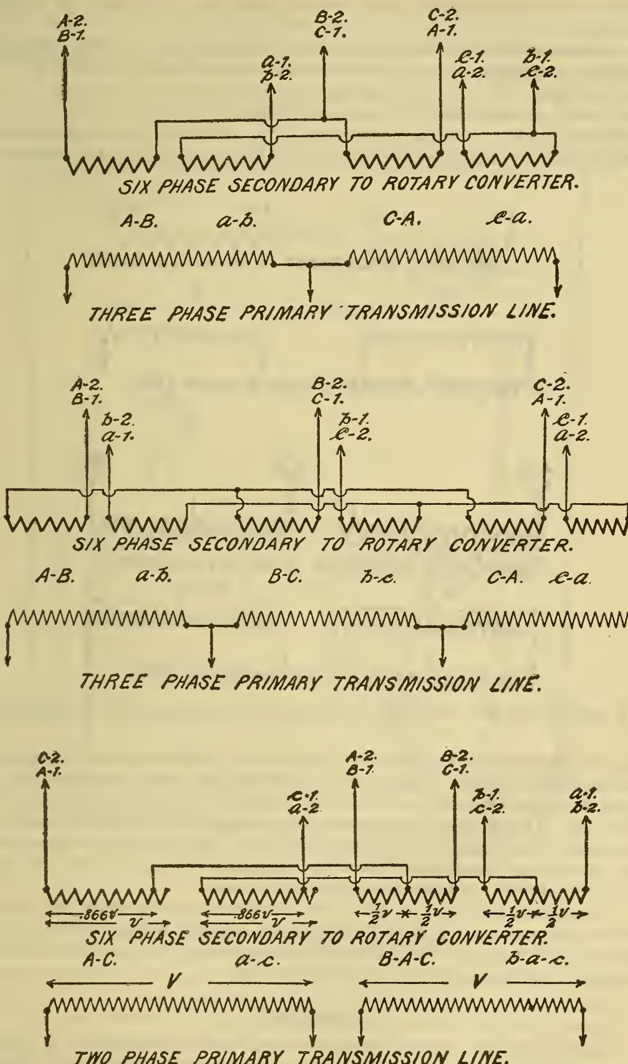


FIGS. 208 TO 211.—TYPES OF ROTARY CONVERTERS.

points, see Fig. 207, alternating current can be delivered externally. If both commutator and collector rings are used the machine can deliver both direct current and alternating current at the same time, in which case it is a double current generator. If instead of being driven by external power, it is driven as a direct-current or synchronous alternating-current motor, and at the same



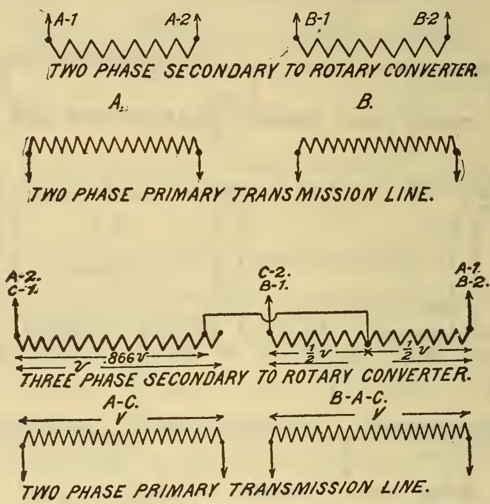
Figs. 212 to 215.—Transformer connections for rotary converters.



FIGS. 216 TO 218.—TRANSFORMER CONNECTIONS FOR ROTARY CONVERTERS.

time delivers alternating or direct current from the other end, it is a rotary converter.

The armature connections of rotary converters are shown in Figs. 208 to 211. Letters represent phases, and numbers the first or second wire of each phase. In the three-phase and six-phase combinations, two phases are combined in each wire, and in the latter the large and small lettered phases are from the same transformers. (See transformer connections, Figs. 216 to 218.) The fields of rotary converters are connected to the direct current side except in case the rotary con-



FIGS. 219 AND 220.—TRANSFORMER CONNECTIONS FOR ROTARY CONVERTERS.

verter is started from the alternating current side, in which case they are preferably separately excited. Transformer connections for rotary converters may be made in a multitude of ways, the most common of which are shown in Figs. 212 to 220. As polyphase transformers are not used in this country, only connections for single-phase transformers are given. In the six-phase connections, the single-phase transformers have two secondary coils apiece, each of which is connected to one of two three-phase combinations.

Rotary converters may be used with compound wound fields the same as ordinary generators. In order to make them regulate well, however, it is necessary to insert reactive coils in the alternating current line, unless the line and generator reactance may be used for this purpose.

BELTS.

Leather belts are generally preferable to others for both damp and dry places. Where the belts must work in steam, they should be made of rubber, as the ordinary waterproofing used on leather belts will not stand the excessive heat.

Leather belts are made in one, two or three ply of from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. thickness each, weighing from 13 oz. to 16 oz. per square foot per ply. On main drives, a first class belt only should be used. Fig. 225 shows a test of a 30-lb. belting butt (this being the average weight used for heavy belting). The backbone runs down

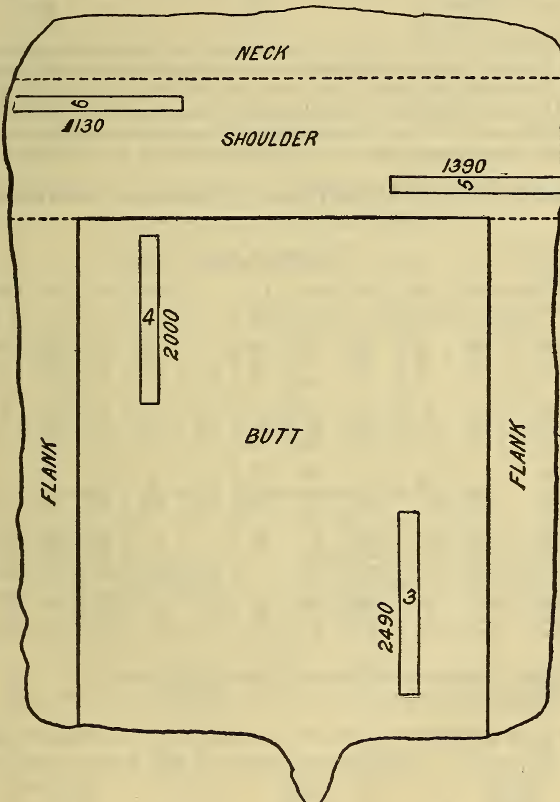


FIG. 225.—PARTS OF HIDE FOR BELTING.

through the center of the figure. The small sections Nos. 3, 4, 5 and 6 were 18 ins. long by 2 ins. wide. The figure shows that to obtain a first class belt it must be made entirely of centers, *i. e.*, only the butt should be used, and shoulders and flanks should be entirely excluded.

The best belting should be short lap, with no piece more than 54 ins. long, including laps. The weights should be as in the table on next page:

Weights of Belts.

Width. Inches.	Single Belts Oz. per sq. ft.	Double Belts. Oz. per sq. ft.
1 to 2	13	26
2¼ to 4	14	28
4½ to 5½	15	30
6 and over	16	32

Single belts 6 ins. wide or less, should have laps between 3½ ins. and 6 ins. long; for wider belts no lap should exceed in length by over 1 in. the width of the belt. For double belts, laps should be 3½ in. to 5½ ins. long. Laps should absolutely have no filling strips. Single belts should have an ultimate tensile strength of 3600 lbs. per sq. in., and double belts should have 4000 lbs. per sq. in. If tests are made, the average of three pieces selected at random, should be taken.

HORSE POWER TRANSMITTED BY DOUBLE LEATHER BELTS.

(1 INCH WIDE, 550 FT. PER MINUTE=1 HP).

Speed in Feet per Minute.	Width of Belt in Inches.										
	4	6	8	10	12	14	16	18	20	22	24
	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H.P.	H. P.
400	2¾	4¼	5¾	7¼	8½	10	11½	13	14½	16	17½
600	4¼	6½	8¾	11	13	15	17½	19½	22	24	26
800	5¾	8½	11½	14½	17½	20½	23	26	29	32	34½
1000	7¼	11	14½	18¼	21½	25½	29	32½	36	40	43½
1200	8½	13	17½	22	26	30½	34½	39	44	48	52½
1500	10¾	16¼	21¾	27¼	32½	38	43½	49	54½	60	65½
1800	13	19½	26	32¾	39	45½	52	59	65½	72	78½
2000	14½	21¾	29	36½	43½	50½	58	65½	72½	80	87
2400	17¼	26	34¾	44	52½	60½	69½	78½	88	96	105
2800	20¼	30½	40½	51	61	71	81	91½	102	112	122
3000	21½	32½	43½	54½	65½	76	87½	98	108	120	131
3500	25½	38	50¾	63½	76	89	101	114	127	140	153
4000	29	43½	58¼	72¾	87	101	116	131	145	160	174
4500	32½	49	65	82	98	114	131	147	163	180	196
5000	36½	54½	72¾	91	109	127	145	163	182	200	218

NOTE.—The belts are not supposed to be unduly strained.
For single belts estimate only two-thirds as much as for double belts.

Pulley Dimensions to Avoid Abnormal Belt Bending Strains.

No. of Ply.	Min. Pulley Diameter.	Min. Ratio of Diam. to Width.
Single	3 ins.	Immaterial
Double	6 ins.	3 : 4
Triple	10 ins.	1 : 1

The power transmitted is dependent on the arc of contact. If the belts are very oily, the power may be reduced one-half. Paper pulley coverings or paper pulleys generally increase the power obtainable by 10 per cent to 20 per cent. The power that can be transmitted by belting is greatly increased by the use of Cling Surface dressing which increases the life of belts by decreasing the wearing off of the surface of belts due to slippage. Belts which are not horizontal will generally tend to slip on the lower pulley if worked at their maximum power. The arc of contact is increased by having the slack side of the belt on top and this method is, therefore, preferable. All pulleys should have crown faces unless it is intended to shift the belts over them.

Belts, particularly on long drives, sometimes give trouble by wobbling from side to side. This may be due to vibration or movement in the shafts or pulleys to which they run, or it may be caused by the belt being stiff and requiring too much force to fit it over the crown. In the latter case washing once a week on the side next the pulley with one part of beef tallow to two of castor oil mixed warm with a little pulverized rosin, until the leather is pliable, will generally remedy the trouble. Belts may also run badly if the pulleys are not properly aligned, are untrue or are out of balance. Trouble will also occur if the belt is not made or fastened truly. Waves in the belt are often caused by irregular power or untrue pulleys, but most heavy belts tend to wave slightly.

The length of drive, *i. e.*, the distance between centers of driving and driven shafts, may be widely varied according to necessity. If a belt is too short it has no elasticity; if too long, it has a tendency to wobble or wave; but the limits are quite broad.

Center Distances for Belt Drives.

WIDTH OF BELT (INCHES).	CENTER DISTANCE (FEET).		
	Minimum	Preferable	Maximum
3	4	8	25
6	6	12	30
12	9	17	32
18	11	20	34
24	12	22	37
36	15	25	40
48	17	30	45
60	20	35	50

SHAFT KEYS AND BEARING CENTERS.

Shaft Diameter. Ins.	Size of Keys for Couplings and Pulleys.	Proper Distance between Bearing Centers, Line Shafting. Feet.	Proper Distance between Bearing Centers, Jack Shafts. Feet.
$1\frac{3}{16}$	$\frac{7}{32} \times \frac{7}{32}$	$5\frac{1}{2}$	$4\frac{1}{2}$
$1\frac{7}{16}$	$\frac{7}{16} \times \frac{7}{16}$	$6\frac{1}{2}$	$5\frac{1}{4}$
$1\frac{11}{16}$	$\frac{7}{16} \times \frac{7}{16}$	7	$5\frac{1}{2}$
$1\frac{15}{16}$	$\frac{7}{16} \times \frac{7}{16}$	$7\frac{3}{4}$	$6\frac{1}{4}$
$2\frac{3}{16}$	$\frac{9}{16} \times \frac{9}{16}$	$8\frac{1}{2}$	$6\frac{3}{4}$
$2\frac{7}{16}$	$\frac{9}{16} \times \frac{9}{16}$	9	7
$2\frac{11}{16}$	$\frac{11}{16} \times \frac{11}{16}$	$9\frac{1}{2}$	$7\frac{1}{2}$
$2\frac{15}{16}$	$\frac{11}{16} \times \frac{11}{16}$	10	8
$3\frac{7}{16}$	$\frac{11}{16} \times \frac{11}{16}$	11	$8\frac{3}{4}$
$3\frac{15}{16}$	$\frac{13}{16} \times \frac{13}{16}$	$12\frac{1}{2}$	10
$4\frac{7}{16}$	$\frac{13}{16} \times \frac{13}{16}$	$13\frac{1}{2}$	$10\frac{3}{4}$
$4\frac{15}{16}$	$\frac{13}{16} \times \frac{13}{16}$	$14\frac{1}{2}$	$11\frac{1}{2}$
$5\frac{3}{8}$	$\frac{13}{16} \times \frac{13}{16}$	15	12
$5\frac{7}{8}$	$\frac{15}{16} \times \frac{15}{16}$	16	$12\frac{3}{4}$
$6\frac{3}{8}$		17	$13\frac{1}{2}$
$6\frac{7}{8}$		18	$14\frac{1}{2}$
8		20	16

DIMENSIONS OF HEAD OR JACK SHAFTS.

Shaft Diameter. Ins.	Revolutions per Minute.									
	100	125	150	175	200	225	250	300	350	400
	Horse Power of Jack Shafts.									
$1\frac{3}{16}$	1.7	2.1	2.5	3.	3.4	3.8	4.2	5.	5.9	6.7
$1\frac{7}{16}$	3.1	3.8	4.5	5.3	6.	6.9	7.6	9.1	10.6	12.
$1\frac{11}{16}$	4.5	5.6	6.8	7.8	9.1	10.2	11.2	13.6	15.7	18.2
$1\frac{15}{16}$	7	8.7	10.5	12.2	14.	15.7	17.5	21.	24.5	28.
$2\frac{3}{16}$	9.8	12.5	14.7	17.	19.5	22.	25.	29.5	34.	39.
$2\frac{7}{16}$	14.	17.5	21.	24.5	28.	31.5	35.	42.	49.	56.
$2\frac{11}{16}$	18.5	23.	28.	31.	37.	41.	45.5	56.	62.	74.
$2\frac{15}{16}$	24.	30.	36.	41.5	47.5	53.5	59.5	71.	83.5	95.
$3\frac{7}{16}$	38.	47.	56.5	66.	75.5	85.5	94.5	113.	132.	151.
$3\frac{15}{16}$	56.	70.	84.	98.	112.	126.	140.	168.	196.	224.
$4\frac{7}{16}$	80.	100.	120.	140.	160.	180.	200.	240.	280.	320.
$4\frac{15}{16}$	109.	136.	164.	191.	218.	246.	273.	328.	382.	437.
$5\frac{3}{8}$	146.	182.	218.	255.	291.	328.	364.	436.	510.	582.
$5\frac{7}{8}$	189.	236.	283.	330.	378.	425.	472.	567.	661.	755.
$6\frac{3}{8}$	238.	297.	357.	416.	475.	535.	595.	713.	832.	950.
$6\frac{7}{8}$	294.	367.	440.	514.	587.	661.	735.	880.	1030.	1177.
8	448.	560.	671.	783.	895.	1010.	1120.	1345.	1570.	1790.

Two or three belts may be run tandem, but where the pulley diameters are small the belts should not touch each other at points on the drive. Where belts are run tandem, the maximum power of each belt is not reduced, but rather increased.

PULLEYS.

Pulleys are usually made in two weights for single or heavy belts. Crowns of pulleys should be from $\frac{1}{80}$ of the face for small or slow-running pulleys, to $\frac{1}{200}$ of the face for pulleys of 24-in. face and over. The latter figure is quite usual in large dynamo pulleys and gives entire satisfaction. The increase in diameter at the crown is twice the amount given. Where the crown is too high with a fast running belt, the latter is liable to leave the edges of the pulley and thus concentrate all the strain and wear on the belt center. Pulleys and clutches should be balanced. Set screws should have cup ends. The bore should be just large enough to fit closely on the shaft.

Pulley centers and not edges should be aligned. Of course it is necessary to align from the edges, but allowance should be made where width differs, so as to bring the centers in line.

Contrary to general ideas, belts do not "tend to climb to the high side of pulleys"; but where two shafts are not parallel, the belts will run on both pulleys toward the low side, *i. e.*, toward the point where the shafts are nearest together.

Shafting.—Counter shafts are usually made in lengths of 24 ft. or less. They should be straight before erection, and should be properly supported so that their hangers can not shake or vibrate. Journals are preferably made "self-oiling."

ROPE DRIVES.

The limit of belt transmission for railway work is in the neighborhood of 500 hp. Beyond this power rope drives should be resorted to for transmission. Curves herewith, Fig. 226, give the power that can be transmitted by manila rope.

The English method of independent ropes driving in multiple is not successful in railway work, for the reason that unequal tension causes undue strains to fall on the ropes having the greatest tension. For the variable railway load, American practice is to have a continuous rope wound around the grooves of driving or driven pulley grooves, and a slack loop taken from one side of the drive, which is held in tension by passing around a tension pulley and kept taut by weights. As the diameter of pulleys decreases, the wear on the rope increases. The table herewith gives the smallest pulley that should be used; larger diameters than those given should be employed where possible.

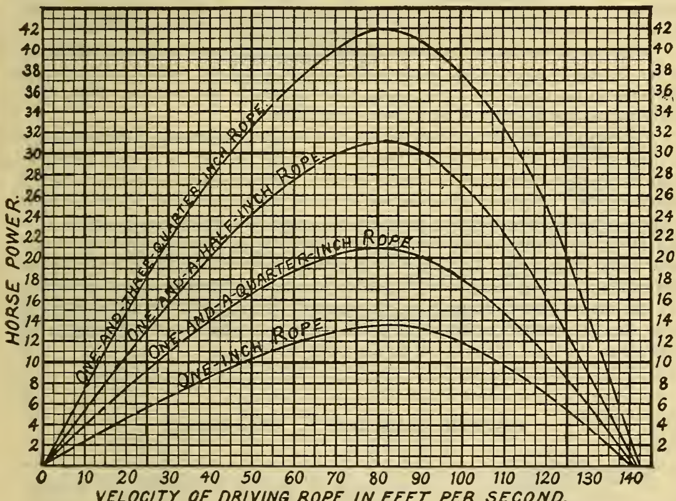


FIG. 226.—CURVES FOR POWER TRANSMISSION BY ROPE DRIVING.

DIAMETER OF PULLEYS AND WEIGHT OF ROPE.

Diameter of Rope in Inches.	Smallest Diam. of Pulleys, in Inches.	Length of Rope to Allow for Splicing in Feet.	Appox. Weight in Lbs. per foot of Rope.
½	20	6	.12
⅝	24	6	.18
¾	30	7	.24
⅞	36	8	.32
1	42	9	.49
1¼	54	10	.60
1½	60	12	.83
1¾	72	13	1.10
2	84	14	1.40

POWER STATION SWITCHBOARDS.

The location of the switchboard should be central with respect to the units it controls. In stations of over 8000-hp output or twenty-five feeders a switchboard attendant is generally required. Here the elevation of the switchboard in a gallery saves floor space and gives the attendant view of the generators he controls. The "unit system" where the generator panel is located adjacent to the generating unit, cutting down the internal conductor cost and giving the engineer electrical as well as steam control of the unit will prove useful where large units are installed. In this case, the feeder circuit-breakers can be operated by pneumatic control for distant parts of the station, and the feeder panel board located conveniently near the distribution wire tower or underground ducts.

In the usual methods of construction the generator panels consist of an ammeter, circuit-breaker, quick break main switch, equalizer switch, voltmeter for throwing in the machines, a regulating rheostat and a field switch. Figs. 227 to 230 show the forms adopted by various companies.

The switchboard surface may be selected of slate, enameled or marbleized, or of marble. The thickness should not be less than 1¾ ins. for a 20-in. panel and 2 ins. for a 26-in. panel, as the circuit-breaker in flying open is liable to fracture thinner slabs. They should be secured to iron framing made of T's or L's using asbestos washers as a bedding between the slate and its support. Slate slabs should not be secured to wooden verticals, as warping of the supports will eventually crack the panels The edges of the panels, have usually ¼-in. bevel, and are fastened by finished hexigon bolts passing through the panel and iron backing.

Bus-bars should be figured for the current density given by table herewith. They should be rolled medium hard and insulated from a cast iron supporting bracket on the back of the board by slate or porcelain.

COPPER BAR DATA. (Bus-Bars.)

Size.	Amperes.	Circular Mils.	Square Mils.	Ohms per Foot.	Weight per Foot.
1 × ¼ in.	433	318,310	250,000	.0000336	.97
1¼ × ¼ "	530	397,290	312,000	.0000269	1.21
1½ × ¼ "	626	477,465	375,000	.0000223	1.45
1¾ × ¼ "	725	556,400	437,000	.0000192	1.70
1¼ × ⅜ "	676	596,830	468,750	.0000179	1.82
1½ × ⅜ "	798	716,200	562,500	.0000149	2.18
1¾ × ⅜ "	916	835.600	656,250	.0000128	2.54
2 × ⅜ "	1,035	954,930	750,000	.0000112	2.92
2¼ × ⅜ "	1,154	1,074,300	843,750	.00000995	3.27
2½ × ½ "	1,500	1,591.550	1,250,000	.00000672	4.86
2½ × ⅝ "	1,715	1,989,440	1,562.500	.00000537	6.07
2 × ½ "	1,222	1,273,210	1,000,000	.00000840	3.89
No. 0000 B. & S.	257	211.600	....	.0000505	.64
½ in. Round	305	250.000	....	.0000428	.76
⅝ " "	426	390,625	....	.0000273	1.18
¾ " "	560	562,500	....	.0000190	1.71
1 " "	861	1,000.000	....	.0000107	3.05

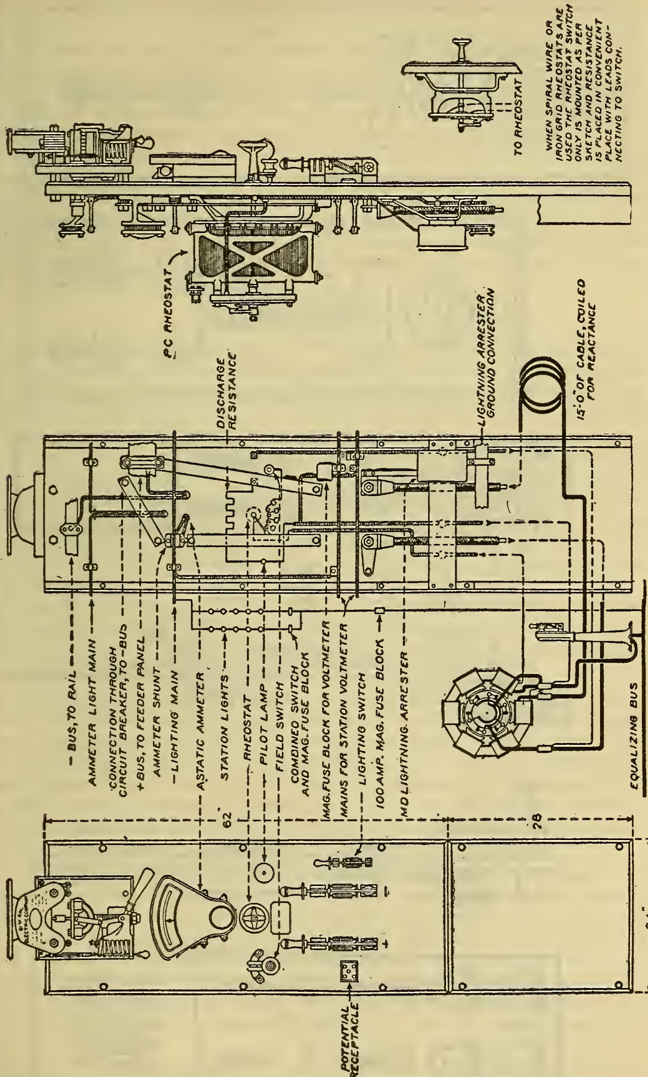


FIG. 227.—GENERAL ELECTRIC RAILWAY PANEL, 300 TO 1,800 AMPERES.

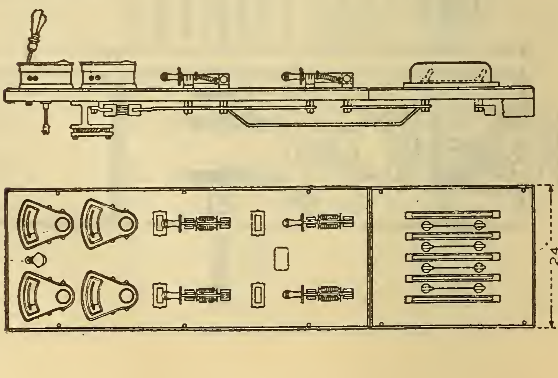


FIG. 228.—GENERAL ELECTRIC FEEDER BOARD WITH FUSES.

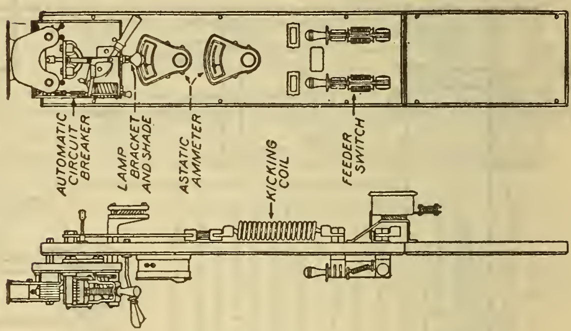


FIG. 229.—TWO RAILWAY FEEDERS FROM ONE CIRCUIT BREAKER.

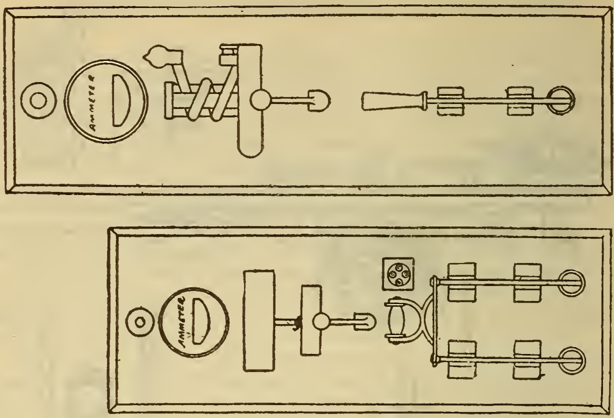


FIG. 230.—WESTINGHOUSE RAILWAY FEEDER AND GENERATOR PANEL.

They should be connected together by lapping, and iron bolts used for bringing these surfaces together, which can be figured safely with smooth bus-bars to carry 190 amps. per square inch of contact surface. The connections between the bus-bars and switches, etc., are preferably made by a copper link clamped between the bus-bar, and between nuts threaded on the stud projecting behind from the switches, circuit breakers or ammeters. The current density should not exceed 60 amps. to 100 amps. per square inch on thread and nut surfaces.

Railway switches should have at least 4 ins. between breaking terminals, and should be provided with an auxiliary snap or carbon break to shunt the current carried by the contact surface, and so reduce injurious arcing effects. The copper contact area should be 60 amps. to 80 amps. per square inch of switch contact surface with parallel, well-adjusted switch surfaces. A composition machine-finished lug held down by an iron bolt should not be expected to carry more than 120 amps. per sq. in. of contact surface.

INSTRUMENTS.

Ammeters.—The ammeter should be dead beat if possible, especially for the generator, and have a full scale reading 35 per cent to 60 per cent greater than the maximum output of the generator, in order to prevent overloads damaging the instrument. It is useful to have the manufacturers mark a red line on the dial of the instrument for full load amperes on the generator.

Where shunts are used, they are connected in the bus behind the board and the leads and shunts marked with the number of the instrument. Care should be taken that the corresponding instrument should only be used with a given shunt. For main ammeters the shunt-type instrument is generally used and the shunt inserted in the main bus as it passes from the generator panel boards to the feeder panel boards. Ammeters are not essential on feeder boards, where the circuit-breaker is reliable and their expense can be saved by introducing a plug device, that can be plugged into the bus side of any feeder switch, on which readings are to be taken, and the current diverted through the common shunt to the ammeter when the feeder switch is opened. This saves space on switchboard as well as reducing the cost.

Voltmeters. There are generally two of these, reading exactly alike on each board. They can be mounted on a swinging bracket so that they can be seen from any part of the board. One is used to maintain the station voltage, and the other to bring the machines to the bus-bar potential. Before throwing machines together there is usually provided a receptacle into which a voltmeter plug is inserted, when the machine is to be adjusted in voltage so that one voltmeter is sufficient for all the generators. For throwing in, where two pressure boards are used, three voltmeters are required.

Wattmeters. Wattmeters should be installed where records of output are to be kept. Periodic readings of the ammeter and voltmeter multiplied together invariably give a result from 20 per cent to 60 per cent above the average watts; and some remarkable station performances have been accounted for from this cause. The natural tendency is to read the ammeter at its maximum swing. The wattmeter should be carefully screened from magnetic effects from the bus-bars which may throw it out of calibration. With large units it is the modern railway station practice to have a wattmeter on each unit so that the depreciation on the units can be averaged.

Circuit-Breakers. To prevent violent overloads on the generator, or to take current off a ground on the line, the automatic circuit-breaker is ordinarily necessary, although fuses are sometimes used instead of circuit-breakers on feeders. The circuit-breaker should respond to a rise in current above its set value in amperes, and open the circuit which it protects; the arc formed on breaking should be taken care of by auxiliary contacts of carbon or a magnetic blow-out. The contacts should be kept in good order, so that the friction between their surfaces will not increase the time constant and so strain the generator, or on feeders throw the generators instead of the feeder breaker. A circuit-breaker should be capable of breaking a circuit before a Weston dead beat ammeter will record 100 per cent over the circuit-breaker's set current value.

Switchboard Connections.—In modern railway practice the positive side of the railway generator armature should be connected to the trolley, through the series winding of the generator. The equalizing connection is taken from the middle point of the switch to the equalizing bus, Fig. 231, but the present practice in power stations is to equalize at the dynamo with the equalizing switch either mounted on the frame of the dynamo itself, or on a pedestal by the side of the dynamo. In other cases again, the equalizer is tied together permanently between all the dynamos. The disadvantage of having the equalizer opened is that there is a danger of the machine being thrown in circuit before it is equalized. In order to provide against this accident, several suggestions have been made. One is to make the switch at the dynamo double pole, carrying both the equalizer and positive connections, throw the generator in first; another method has been used where the throttle of the engine is connected to the equalizer switch, so that before the throttle is open, the switch is closed; and the generator cannot be thrown in before it is equalized. For balancing and adjusting compound generators see page 48.

The field of the railway generator may be connected up in two ways: the one shown in full lines in Fig. 231 is the bus-bar excited method, and the one shown in dotted lines is the self-exciting method. When a large number of generators are to be handled, a dynamo galvanometer or voltmeter is connected across the dynamo terminals of the dynamo switch, instead of plugging in the voltmeter in order to show when the generator is of the right potential to be thrown in. It is also usual to allow for a panel between the dynamo and feeder panels, on which to mount the main ammeter, integrating wattmeter, voltmeters and pressure switches. The positive bus-bar only is taken to the feeder board, and the feeders are provided with a single-pole switch, ammeter, circuit-breaker and reactance coil to choke back any lightning discharges, and force the arrester to operate. The dynamo panel should be provided with a small double pole, lighting switch where the station is lighted from the power generators, so that any generator can light the station independently of the power bus-bar. This lighting circuit should be looped inside of the circuit-breakers. The present practice indicates that the best results are obtained when the lightning arresters are located as near the point where the feeders enter the station as possible. Behind the switchboard is not the proper place for the lightning arresters as a rule.

The panel form of construction is now universally adopted, the apparatus being mounted on an upper panel, with a foot plate, about 20 ins. below it. These panels are made interchangeable for the different units and feeders, and the extension of a switchboard, only requires that the bus-bar and iron frame be extended, giving a very flexible method, and amply providing for the future growth of the system. It is useful in some cases to be able to separate the feeder systems, so that they can be supplied by independent generators, where extra demands of traffic require a higher potential to be obtained on the congested part of the system To effect this result, the dynamo should be provided with a double-throw switch, and the equalizing system should also be double, with a double-throw equalizer switch. If double-throw feeder switches are also provided, the feeders can be operated on independent generators when required. It is the usual pract-

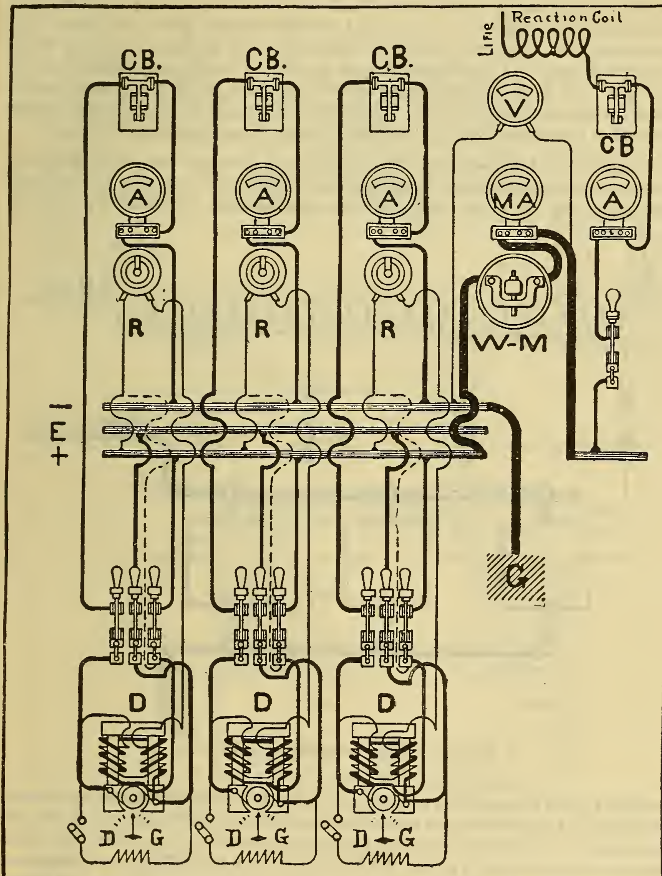


FIG. 231.—DIAGRAM OF RAILWAY SWITCHBOARD CONNECTIONS.

ice to tie all rail and return grounds to a common negative bus-bar, but to reduce electrolysis, in some cases the ground returns which are tapped directly to the water or gas pipe systems, are brought to one ground bus-bar, and the rail or return feeders are connected to a separate one.

The conductors behind the board are supported on porcelain insulators, or threaded through porcelain blocks. All conductors over No 0 should be stranded and the field wires should in all cases be a stranded conductor. In some cases asbestos or lead covered leads are used. Where bare rubber is employed for the insulation great care should be exercised to prevent oil from reaching these conductors, as fire has originated in several railway stations from this cause. Exposed terminals of different potential adjacent to one another, especially where the line is subject to lightning storms, should be taped and insulated, or so shielded that no spark can jump between them, for when the circuit-breaker opens on overloads, there may be quite a rise in potential on the dynamo, which sometimes starts a damaging flaring arc between exposed adjacent surfaces.

Lightning Protection.—There are several principles employed to protect the generators and apparatus from lightning discharges. The leak arrester consists essentially of a water resistance connected between the positive trolley and

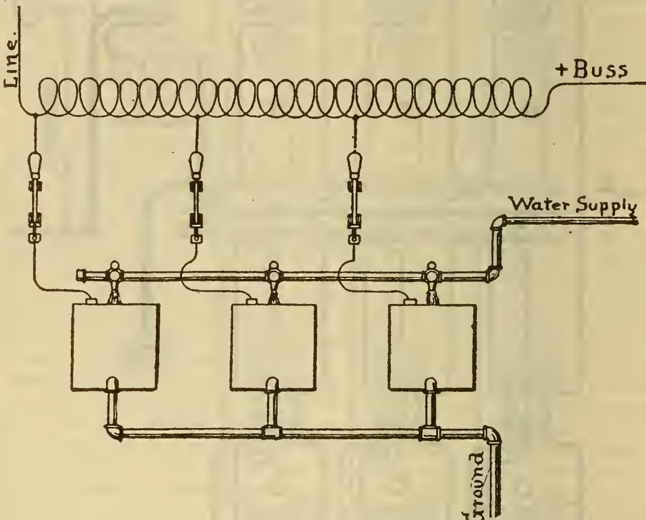


FIG. 232.—TANK LIGHTNING ARRESTER.

ground, so that the potential between the feeder system is maintained at 500 volts difference. Any tendency for static discharge to select the feeder wire as its path to ground, is neutralized before an abnormal difference of potential can exist. The tank arrester, shown in Fig. 232, is plugged into the circuit at the approach of a thunder storm. Three tanks are usually employed, so that if a discharge passes one, it is dissipated through the other and leaks to ground.

The magnetic forms of arresters have an air gap about $\frac{1}{16}$ in. over which the static sparks jump to ground. The main current passes around an electromagnet, whose field of force is so arranged as to blow out of this gap the arc formed by the line current following the static spark. Every obstruction offered to the flow of this discharge by the ground wire subjects the station apparatus to an electrostatic stress, tending to break it down at its weakest point, and every means should be used so that the lightning discharge can jump the spark gap of the arrester and pass to ground. The high frequency which a discharge possesses

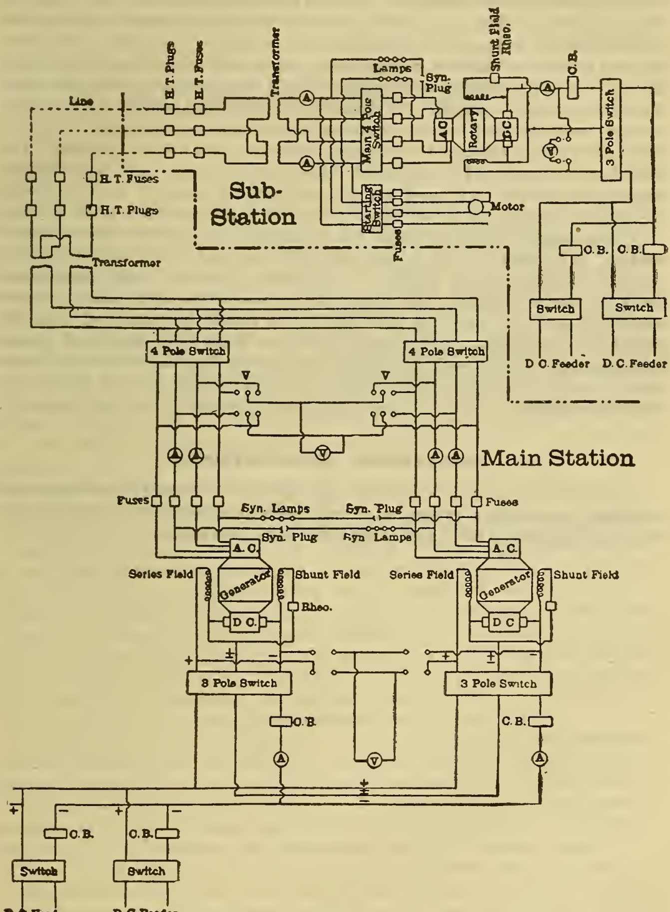


FIG. 233.—CONNECTION BETWEEN MAIN AND SUB-STATION, TWO-PHASE SYSTEM.

gives it a tendency to travel on the surface, rather than on the interior of the wire, and in this way choke its own passage. This effect increases as the diameter of the wire increases, and consequently only a small wire is used for the ground conductor, No. 6 being the usual size. A bend in a conductor greatly increases its self induction, consequently the wire should be as straight as possible from the point of connection at the lightning arrester to the ground connections. Carrying this wire parallel or near masses of iron will also tend to retard by self-induction the passage of the discharge to earth. To use a water pipe system for earth is not the best practice, but where it is necessary an iron lug can be clamped to the water pipe and the contact surfaces amalgamated, the ground wire being soldered into this lug. After the connection is made, it should be painted over with two coats of air-drying asphalt varnish. No ground connections that are used for any other purpose should be used for the lightning arrester ground. No part of an iron structure or piping through the building should be used for this purpose. The ground conductor should be connected to the water system as near its entrance to the earth as possible. A ground near running water or naturally moist earth will give the best results, but in all cases it must be below the frost line. If these conditions cannot be secured, a hole can be sunk in the ground until water is reached. A copper plate two by two feet, with the conductor firmly soldered to it, will in ordinary cases be adequate for lightning grounds. Loose waste metal does not materially increase the actual contact area of the earth plate. If such material is used for the earth plate, each piece should be connected with the ground conductor itself. The best material to use to get a low resistance ground is broken coke, which should be tamped well in the bottom of the hole to the depth of about 2 ins. The copper plate should then be laid on, and about 4 ins. more coke tamped well over it. Earth can then be thrown in and tamped lightly.

POLYPHASE SUB-STATIONS.

Fig. 233 shows the main station and sub-station switchboard connections for a two-phase transmission system, with an alternating-direct-current generator at the generating station and a rotary converter at the sub-station.

SECTION V.—THE LINE.

Direct current distribution should be employed on roads not exceeding six miles radius with moderately condensed traffic and eight miles radius with grades and light traffic. For roads which reach further from the power station than this, the question of the most economical method of distribution will have to be solved for each individual case, as there are too many variables entering into the problem to make a general solution possible. One question in the design of the system for larger territories when the principal part of the road lies within the six mile radius is whether to use more copper to expand the area to, say, nine and one-half miles, or use boosters with less copper For distant distribution, the general method of solution is given below and also data, from which the copper line can be figured. The cost of the different methods should be compared with that of the direct feeding method as a criterion. The area to which the estimates for alternating current distribution should be applied is certainly beyond the five mile radius, and the capital investment and cost of copper for feeding the outlying territory alone should be considered.

The elements involved in the consideration of what would be the best system of transmission to use are the fixed and operating charges. The former include the cost of line copper for permissible line drop, additional cost on pole line to carry copper and the cost of bonding for the return circuit; the latter, the interest on capital, the depreciation on the line and the cost of line losses per annum. To make the substation profitable the cost of these two charges should be greater than the sum of the cost of the substation building, the boiler, generator, switchboard, cost of line, bonding, and the interest charges on the substation investment, depreciation charges, cost of supplies, labor charges and reduction in main station efficiency due to loss of load.

In comparing a direct transmission of 550 volts against a rotary converter substation, the same principle holds good. Compare the original cost of the 550-volt distribution system and the operating charges, as given above, against the cost of building the rotary converter substation, the additional cost of generators in the power station, cost of rotary converters and static transformers, cost of transmission line and insulation and switchboard, and the interest, depreciation, attendance and supplies, as well as the annual cost of transformation losses.

The booster overcomes the line drop, and the economy of using a booster to produce proper potential at distant points depends upon the relation between the copper cost, depreciation and transmission losses for direct current distribution, and the booster cost, depreciation and transmission losses. It is not usual that boosters operating continually for any considerable load will show a better investment than copper; but for transient loads they do make an economical showing. The distribution can be carried by copper alone on roads between six and ten miles radius, where the equipments are operated by feeders only under normal loads.

Data will be given in this chapter to determine the copper line costs; and equivalent rotary or substation construction could be estimated from the manufacturers' quotations for specific performances.

THE MOST ECONOMICAL ARRANGEMENT OF FEEDERS.

The next matter to be decided in line construction is the proper amount of copper to use and its most economical disposition. We will first view this question from commercial considerations. Returns from the investment in copper may come from several sources. The first and direct loss caused by a deficiency of copper in a feeder system is in the loss of energy; second, in the increased depreciation of the car equipment due to the higher temperatures attained by motors operated by low voltages; third, in the added expense of operating more equipments where a given headway between them is maintained, due to the lower maximum speeds and slower acceleration under low voltages.

In connection with the energy it can be seen that the smaller we make the feeder for a given load, the greater the loss and the less will be the fixed capital charges against this feeder per annnum. On the other hand, the cross section may be increased until the interest charges are largely in excess of the energy saved. Lord Kelvin determined that the most economical sized feeder to use was the one in which the annual interest charges were equal to the annual cost of the energy lost, and this is accepted as a general rule for the determination of the proper capital investment in the feeder. To the cost of feeder should be added the cost of its insulation and pole line or of conduit, and the interest charge can be fixed by local conditions.

The price per unit of energy generated in the station should be based on that charge for which a power station could sell all its output without profit or loss. The method for computing this charge is given on page 267. Taking this prime value, the cost for the losses on the line will be some amount less than this cost, per unit lost, depending upon cost of this additional production of energy, and the cost varies on each plant for this loss, but the cost of increasing a load 10 per cent on a station will make little difference in its consumption of coal, oil and water, except where an extra unit has to be operated to maintain the usual 25 per cent overload margin allowed in operating capacity; and under these conditions the losses in this added unit are chargeable to the line losses. Strictly speaking, the fixed charges belong to that portion of the energy of the station which produces a revenue, and again the increased loading of a unit brings up its efficiency, and this line loss is reflected in decreased cost of the total output.

If these costs and current deliveries are determined for any road, it is very easy to construct a table in which the cost of the energy lost is compared with the capital charges, and this determines what size of wire can be most economically used. The next and most difficult question is the fixing of the current reqnired to propel the car or cars which are fed by the copper to be supplied.

Assume the energy consumption as 1.2 kw-hour per car mile for level track, 28-ft. car body weighing 18,000 lbs., single truck, two G. E. 800 motors with K-2 controller, and speed 10 miles per hour. This, with 500 volts, gives the average of 24 amps. per car for current delivery. On the first step the car would require 60 amps. at 500 volts; but, with this flow of current, a drop will occur over the copper conductors. Say the voltage fell to 450 volts with the controller on the first notch, then the current will be 54 amps. The second notch of the controller cuts out 4½ ohms., and this should largely be taken up by the counter e. m. f. of the motors, which have started and commenced accelerating.

The speed gained on the first notch reduces the current obtained when the second notch is reached, and the greater the feeder drop the slower the acceleration. The greater the amount of energy required to bring the equipment to speed, the higher will be the temperature attained by the motors, and the greater the rate of equipment depreciation and the maximum demand on the power station. These losses and station investment can be reduced by greater line copper investment.

In this problem, both the copper and ground return system have to be considered. Allowing 20 per cent drop, which means an effective voltage delivery of 400 volts to the equipment, the maximum current at starting, which will be on the second notch, can be assumed as about 90 amps. Say that 8 per cent drop is allowed for the ground returns, and 12 per cent for overhead copper; this gives a maximum feeding resistance of ⅔ ohm per equipment. The average demand then is 24 amps. per car, and the maximum demand 90 amps. for the case under discussion.

The effect of grades is to increase both the starting current and also the running current value. The chart, Fig. 234, shows the relation which exists between the traction coefficient, which is plotted as ordinates on the chart, and the watts at 1 mile per ton per hour, which are plotted as abscissæ on the chart. Diagonal lines are drawn across the chart corresponding with grades from level up to 19 per cent, to assist in giving what is really required, i. e., the amperes flowing for different speeds and grades. On the right hand of the chart is given a scale in amperes, assuming the current delivery to the equipment is at 500 volts, for speed of 1 mile per hour. While the current delivery is not a rectilinear function of grade and speed, approximately proportional results can be obtained by multiplying the speed on grades by the wegiht of the car and then by the current given in this chart at the required grade, which will give the total amperes required.

As an example, suppose we have a car weighing 18,000 lbs. climbing a 4 per cent grade at 10 miles per hour, with a track coefficient of 25 lbs. Pass up the vertical line 25 until the diagonal line indicating 4 per cent is reached, then pass horizontally until the 1 mile per hour scale of amperes is reached; this gives 0.42 amps. per ton. For 9 tons this wonld be 0.42 (amps.) × 9 (tons) × 10 (miles) = 37.8 amps. The two other vertical columns at the extreme right of the chart, one 6-mile speed and the other 12-mile speed, give the current required, including 20 per cent loss on the line. For example, assume an 8 per cent grade, 30 track coefficient, car weighing 20,000 lbs., running at 8 miles per hour, at 20 per cent transmission loss. This will give 5.7 amps. per ton, adding ⅓ more for increased speed and multiplying by 10 for weight in tons would give 5.7 × 4 × 3 × 10 = 76 amps. This, of course, is without any rheostat in circuit with the motors. The same problem can be worked out by the table given on page 271.

The following example will illustrate the use of this table:

Example—Given a car weighing 12,000 lbs. loaded; the grade at the point where we wish to know the current is 4 per cent; speed required is 7 miles per hour; traction coefficient on this track is, say, 20 lbs.; motor efficiency is 80 per cent; current delivered at 500 volts. The current taken at this point will be equal to watts in table, shown at intersection of 4 per cent grade and 20 coefficient, multiplied as follows:

$$\frac{198.9 \times 7 \text{ (miles per hour)} \times 6 \text{ (tons weight)}}{.80 \text{ (efficiency)} \times 500 \text{ (volts pressure)}} = 20.88 \text{ amps.}$$

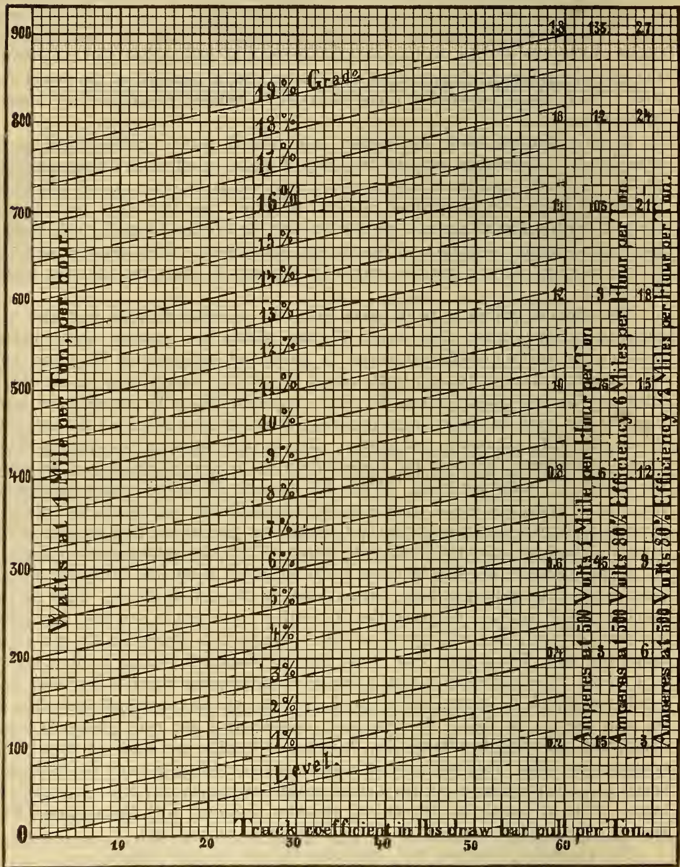


FIG. 234.—CHART SHOWING RELATION BETWEEN TRACTION COEFFICIENT AND WATTS AT 1 MILE PER TON PER HOUR FOR DIFFERENT GRADES.

It is extremely difficult to give the exact speed at which a car will ascend a given grade, for each equipment will fall in speed in mounting a grade until the counter e. m. f. of the motors has been reduced to such a point that the current is sufficient to propel the car up the grade. This point is variable, depending upon the equipment.

In considering the copper service on grades, the cars coming down grade require less current than those ascending, and generally above a 3 per cent grade a car will float with open controller after being started up to speed. It is very important to maintain potential at grades in order that the car can climb the grade at good speed, and to reduce the heating of the motors; and if the schedule can be maintained up grades the motorman will not be called on to make up time by coasting too fast down grade. The usual practice of feeder taps from trolley to feeder every ten or eight poles on levels should, on grades, be reduced to six or four poles, in order to maintain the feeder pressure at trolley wire. The headway of the cars will have to be known in order to get the average current demand, but the average demand is taken care of when provision is made for the maximum demand.

In the operation of a railway it is necessary at times to operate more cars over a section of track than are required by schedule, and fixing the maximum current demand is purely a local problem. The maximum demand is usually figured for a total drop of 140 volts where 500 volts are used at the station, and 150 volts with a 550 station voltage.

There are a number of ways in which the copper investment can be reduced to handle this maximum load, some of which are given on page 276. By estimating the possible number of cars that could be massed together and using the constant given for each individual car, the maximum demand can be determined.

Theoretical Watts Per Ton of 2,000 Lbs. and Per Mile Per Hour, with Various Grades and Traction Coefficients.

Grade Per Cent.	Coefficient, in Pounds Draw Bar Pull Per Ton.										
	12	13.5	15	18	20	25	30	35	40	50	60
0........	23.9	26.9	29.8	35.8	39.8	49.7	59.7	69.6	79.6	99.5	119.4
1........	63.7	66.6	69.6	75.6	79.6	89.4	99.5	109.4	119.4	139.2	159.1
2........	103.4	106.4	109.4	115.4	119.4	129.3	139.2	149.2	159.1	179.0	198.9
3........	143.2	146.2	149.2	155.2	159.1	169.1	179.0	189.0	198.9	218.8	238.7
4........	183.0	186.0	189.0	194.9	198.9	208.9	218.8	228.5	238.7	258.6	278.5
5........	222.8	225.8	228.8	234.7	238.7	248.7	258.6	268.3	278.5	298.4	318.3
6........	262.6	265.6	268.5	274.5	278.5	288.4	298.4	308.3	318.3	338.1	358.1
7........	302.4	305.4	308.3	314.3	318.3	328.2	338.1	348.1	358.1	378.0	397.9
8........	342.4	345.1	348.1	354.1	358.1	368.0	378.0	387.9	397.9	417.8	437.6
9........	381.9	384.9	387.9	393.9	397.9	407.8	417.8	427.7	437.6	457.5	477.4
10........	421.7	424.7	427.7	433.7	437.6	447.6	457.5	467.5	477.4	497.3	517.2
11........	461.5	464.5	467.5	473.5	477.4	487.4	497.3	507.2	517.2	437.1	557.0
12........	501.3	504.3	507.2	513.2	517.2	527.2	537.1	547.1	557.0	576.9	596.8
13........	541.1	544.1	547.1	553.0	557.0	567.0	576.9	586.8	596.8	616.7	636.6
14........	580.9	583.9	586.8	592.8	596.8	606.7	616.7	626.6	636.6	656.5	676.4
15........	620.7	623.6	626.6	632.6	636.6	646.5	656.5	666.4	676.4	696.3	716.2

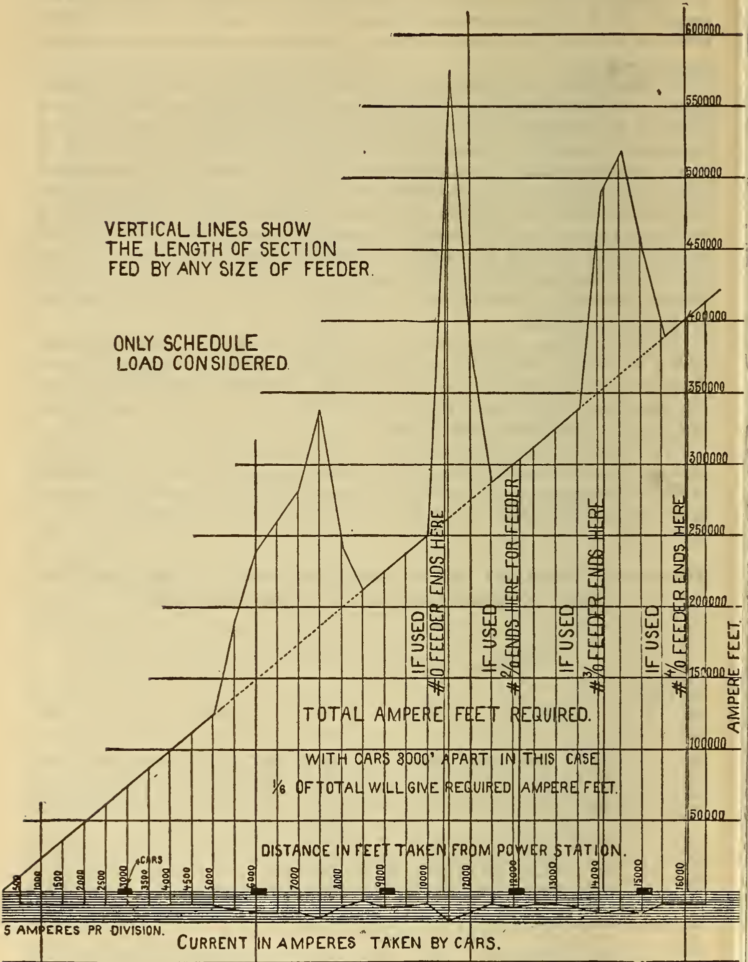


FIG. 235.—DIAGRAM SHOWING THE DISTRIBUTION OF FEEDERS ON A ROAD WITH CARS 500 FEET APART.

PROPORTIONING FEEDERS.

After the current for the feeders has been determined, the next question is the location of the feeding sections and the proper disposition of the copper to get maximum potential delivery. This copper may be in one or several feeders. Where it is combined into one feeder, the cost of copper, per volt drop, is least. The cost of supporting this feeder is less, and the strains which it imposes on the pole line and the surface it presents to wind pressure, are all in favor of the single feeder. The sub-division of the feeders and the connection of these separate divisions to different circuit breakers in the station is for safety. The sub-division of the feeders may be said to have been originally due to the employment of fuses as safety devices. The action of the fuse required the dividing of the feeding systems up into a number of independently fed sections, but the modern circuit breaker, being much more prompt in its action, provides ample safety for the electrical machinery. Fuses, if placed between separate feeders on the line, will open when any section is grounded, so that in rewiring or reconstructing old distribution systems it is desirable to inter-connect the neighboring feeders by fuses, and thus get the most effective use of the copper.

The diagram on page 272 shows the application of this principle of locating feeders to a road 16,500 ft. long, on which the cars are 500 ft. apart with a 12 per cent drop; ordinates are drawn every 500 ft. or for each car, and their length represents the ampere feet required at each point. To apply this diagram to the case of a road with cars a greater or less distance apart the ampere feet required will be inversely proportional to the car spacing; thus with cars 3000 ft. apart the values in ampere feet will be one-sixth of the values given in the diagram. The ampere feet are given in column 15 in the table on page 274, from which the different conductors can readily be selected and applied to find the least feeder cost forthis distribution.

It will be seen from this diagram that the feeding sections grow smaller as the distance increases from the station, so also this method of laying out feeders gives each feeder uniform service. The limiting distances for No. 0, No. 00 and No. 000 feeders, applied to the problem worked out, are shown in the diagram. The ordinates below the datum line show the current consumed by the cars at each point. This current multiplied by the distance from the station, gives the ordinates above the datum line, which are the ampere feet. With a road in which the feeders traverse short cuts, *i. e.* do not follow the trolley line, the problem would have to be arranged so that the distribution takes place from the intersection of the feeder and trolley, and the distance in feet to the station from this point, would be the feeder length.

Wiring Diagram for Simple Transmission.—The diagram on page 275 will give the correct size of wire to use in power transmission, from a distance of 1000 ft. to 25,000 ft., and from no drop to 200 volts drop. On the lower margin of this diagram will be found current in amperes. On the right vertical edge will be found distance in feet. On the left vertical edge will be found volts drop. On the top of the sheet will be found sizes of wire, with a heavy line vertically through the diagram for each size of wire.

Any wiring problem within the values given on the diagram can be solved as follows: Suppose we had 200 amps. to carry 3 miles with 50 volts drop. Start at the bottom of the diagram at 200 amps., follow this vertical line up until it intersects the horizontal line from 50 volts on the left hand vertical scale, pass along the radial line from this point until the horizontal line from 3 miles is met. The vertical line passing through at this point will lead upwards until the scale of

TABLE OF SIZES, WEIGHTS, ETC., OF WIRE.

1	2	3	4	Weather Proof Triple Braided Weights.		7	8	9 Stranding usually Employed. Heavy Type B. W. G. Light B. & S. SIZE OF WIRE.									10	11	12	13	14	15	16	17
Size of Wire in 1-1000 of an inch and B. & S. Gage.	Area in Circular Mils.	Outside Diameter of Stranded Conductor.	Outside Diam. Weather Proof Tripple Braided. Nearest 32nd of an inch	5 Per 1,000 Ft.	6 Per Mile.	Bare Per 1,000 Feet.	Per Cent of Insulation to Total Conductor Weight,	8	Diam .117	9	10	11	12	13	15	16	Breaking Strain in Lbs. Use 1-6 for Line Strains.	Resistance per 1000 Feet. International 5 Ohms at 60° Fah.	Resistance per Mile. International 5 Ohms at 60° Fah.	Distance Wire Will Carry Full Current Capacity with 12% Drop 500 Volts.	Maximum Amps. Carrying Capacity Under-Writer's Rules.	Ampere Feet Capacity of Feeder With 12% Drop.	Weight of Wire Between 100 Ft. Spans,	Wind Area Presented by Each Wire per 100 Ft. Span in Square Feet.
1.000	1,000,000	1.152	1½	3,550	18,744	3,050	16.3	61	...	...	...	...	...	...	...	...	21,190	.01015	.05359	5.920	1,000	5,920,000	355.0	10.6
950	950,000	1.125	1 15/32	3,380	17,750	2,898	16.6	...	...	...	...	...	89	...	...	...	19,950	.01069	.05644	5,850	960	5,616,000	338.3	10.4
900	900,000	1.092	1 13/32	3,215	16,975	2,745	17.1	12	...	...	...	**49**	...	...	...	...	18,300	.01126	.05945	5,800	920	5,336,000	321.5	9.9
850	850,000	1.062	1⅜	3,060	16,120	2,593	18.0	...	...	...	...	...	76	...	...	...	......	.01196	.06315	5,700	880	5,016,000	304.8	9.7
800	800,000	1.035	1 11/32	2,880	15,200	2,440	18.0	.	42	...	.	...	**19**	...	...	...	15,960	.01273	.06521	5,615	840	4,716,600	288.0	9.5
750	750,000	.999	1 5/16	2,713	14,325	2,288	18.5	...	15	...	...	...	**46**	...	...	...	15,598	.01355	.07154	5,550	800	4,440,000	271.3	9.2
700	700,000	.963	1 9/32	2,545	13,438	2,135	19.2	...	...	...	...	...	65	...	...	...	......	.01454	.07677	5,430	760	4,126,800	254.5	9.0
650	650,000	.927	1¼	2,378	12,556	1,982	19.9	...	...	...	...	...	60	...	...	...	......	.01564	.08258	5,330	720	3,837,600	237.8	8.8
600	600,000	.891	1 7/32	2,210	11,668	1,830	20.7	...	...	...	37	...	...	**24**	...	...	12,675	.01695	.08959	5,220	680	3,549,600	221.0	8.6
550	550,000	.855	1 3/16	2,043	10,787	1,878	21.6	...	...	.	...	...	51	...	...	...	......	.01846	.09746	5,125	635	3,254,375	204.3	8.4
500	500,000	.819	1⅛	1,875	9,900	1,525	22.9	...	37	...	...	...	...	...	...	...	10,300	.02034	.10739	5,025	590	2,964,750	187.5	7.9
450	450,000	.770	1 3/32	1,703	8,992	1,373	24.0	...	...	...	...	...	42	...	...	...	......	.02258	.11922	4,880	545	2,659,600	170.3	7.7
400	400,000	.728	1 1/16	1,530	8,078	1,220	25.4	...	...	...	25	...	**12**	...	...	...	8,500	.02539	.13368	4,730	500	2,365,000	153.0	7.5
350	350,000	.679	1	1,358	7,170	1,068	27.1	...	...	...	12	...	...	**25**	...	...	7,400	.02908	.15354	4,590	450	2,065,500	135.8	7.0
300	300,000	.630	15/16	1,185	6,257	915	29.5	...	...	...	...	37	...	...	...	...	......	.03388	.16888	4,430	400	1,772,000	118.5	6.6
250	250,000	.590	29/32	1,012	5,343	762	32.8	...	7	...	...	...	**13**	...	...	...	5,205	.04066	.21468	4,420	334	1,476,280	101.2	6.4
0000	211,600	.530	¾	775	4,092	645	20.1	...	...	...	14	...	**6**	...	...	...	4,798	.04811	.25402	4,000	312	1,248,000	77.5	5.3
000	168,100	.470	11/16	630	3,326	513	22.8	...	...	...	...	5	...	**14**	...	...	4.200	.06056	.31975	3,780	262	990,360	63.0	4.8
00	133,225	.420	9/16	490	2,587	406	20.6	...	...	...	...	6	13	...	...	...	2,821	.07642	.40349	3,575	220	786,500	49.0	3.9
0	105,625	.375	17/32	400	2,112	322	21.1	...	...	...	...	...	6	...	**13**	...	2,568	.09639	.50893	3,375	185	624,375	40.0	3.7
1	83,521	.330	½	306	1,616	255	20.0	...	...	...	...	...	...	...	...	**19**	1,682	.1219	.64363	3,180	156	496,080	30.6	3.5
2	66,564	.291	15/32	268	1,415	205	32.0	...	...	...	6	1	...	...	...	...	1,482	.1529	.80731	3,010	131	394,310	26.8	3.3
3	52,441	.261	7/16	210	1,109	160	31.2	...	...	...	...	6	1	...	...	...	1,174	.1941	1.0095	2,810	110	309,100	21.0	3.1
4	41.616	.231	⅜	164	866	127	29.1	...	...	...	...	...	6	...	**1**	...	895	.2446	1.2914	2,670	92	245,000	16.4	2.6

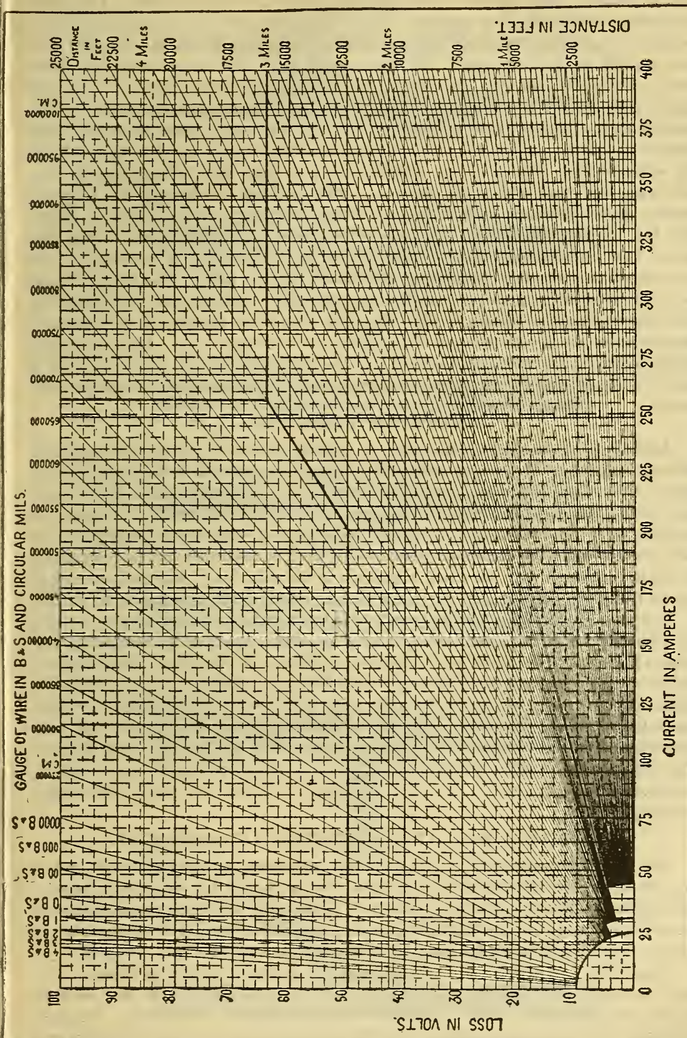


FIG. 236.—WIRING DIAGRAM FOR POWER TRANSMISSION.

wire is reached, and this will be 67,500 circ. mils, the value sought. Any three conditions required of a railroad feeder being known the fourth can be determined graphically by this diagram. For instance, suppose we had No. 0000 wire and wished to find out how far this would take 100 amps. with 75 volts drop. This problem can be solved by finding the intersection of the 100 amps. and 75 volt lines and passing down the radial line intersecting this point until the vertical line extending from the circ. mils scale from No. 0000 wire is reached. Then the horizontal line intersecting at this point from the scale of feet will give the distance in feet that the current can be carried with this wire and with this loss. The problem of finding the current, having given distance, size wire and drop, can be solved as follows: First, find the intersection of the wire with the distance, and then pass along the radial line intersecting at this point until the volts drop is reached. Then the vertical line also intersecting at this point with the radial drop line will lead to a horizontal scale in amperes and satisfy the other conditions of this equation. The other required problem, to find the volts drop when the size of wire, current and distance are given, can be worked out in the same way. The conductor length is given in feet single distance and the diagram should not be used for a metallic circuit; for in that case it shows only half the amount of copper necessary.

MULTIPLE FEEDING.

Another problem that often arises in railway feeders is to find the multiple feeding resistance of several conductors when the current is delivered at one point. The rule for this is to multiply together two resistances, and divide their product by the sum of their resistances. If another conductor is feeding in multiple with these two and the correct resistance of these three conductors in multiple is sought, the combined resistance of the first two must first be determined and then combined with the third conductor in the same way. For tests on copper conductivity see page 33 and for tests on line conductivity see pages 46 and 47.

It is usual to run two feeders from one circuit breaker in the station to each continuous section, but considerable money can often be saved by combining two feeders into one, giving one equivalent cross section of the two. For instance, 2 miles of triple braided No. 0000 wire weigh 8184 lbs., of which about 1600 lbs. is insulation. If now, a single 450,000 circ. mils cable were used instead, it would weigh 8092 lbs., of which only 1000 lbs. is insulation, and the drop of this mile transmission would be lower by 8 per cent than with the two No. 0000 feeders. The tendency in modern line construction is to use larger and fewer feeders, advantages being found in line cost, location of weight on pole, and copper economy.

CONSTRUCTION AND JOINTING OF FEEDERS.

The insulation generally used on wires is known as weatherproof, and it consists of two or three braidings of jute, which should be thoroughly impregnated with a water-proofing compound. The covering and compound should be tough enough to resist considerable abrasion, and there should be no decrease in insulation resistance with 110 volts, after several hours immersion in water.

It has been the practice in the past to tin the wires of stranded cables. Tinning increases the resistance of the wire, for it combines with the surface copper, and the effect is to slightly reduce the conductivity of the wire. There is no reason for tinning copper where weather-proof covering is used, except where the feeder is exposed to salt sea air, and in mining districts where the air is laden with corrosive gases. Where cables are spliced it is very easy to tin the strands before making the splices.

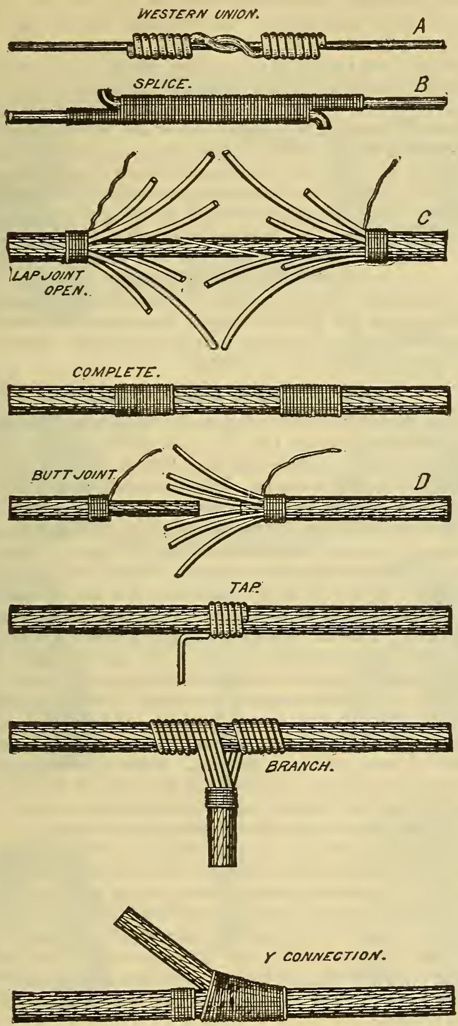


FIG. 237.—LINE SPLICES.

The ordinary Western Union Joint, shown at *A* in Fig. 237, is satisfactory where the wires are No. 0 or smaller. Good results, however, are not obtained with this joint when the wire is larger than No. 0. The best joint in such cases is made by turning the ends sharply at right angles, paralleling two wires, wrapping with No. 12 copper wire, and then soldering the joint, as shown at *B*. Solder is usually poured over a joint of this kind, but care should be taken that the wire is hot when the soldering is done. The best way to heat the joint is to use blow lamps, placing the joint on a board. With a little experience the best results may be obtained with resin as a flux, but soldering acids and compounds are generally used. The lap of the two wires on this splice joint should be at least twelve times the diameter of the wire. If properly soldered, this joint will then be as strong as any other part of the conductor. Exposed joints should be served with at least four layers of adhesive tape, so that the joint will be as well protected as the insulated wire. A splice in stranded cables is usually made by interweaving the strands of the two cables. Several methods often employed are shown at *C* and *D* (Fig. 237), but to make the joint electrically satisfactory each wire should be separately tinned before the two cable ends are interlaced. The connection is then served with No. 20 copper wire, as shown.

THE FEEDER INSULATORS.

In addition to the insulation covering on the feeder wire, a second insulation should be introduced between the feed wire and its mechanical supports. The materials generally used for this purpose are porcelain, glass and compounds of mica and shellac, rubber and asbestos. The mechanical properties of this insulation should be such that it will stand strains without fracture, and that the surface will not absorb moisture. Glass or porcelain is generally used for No. 000 feeders or smaller, but for larger feeders with long spans, exceedingly strong insulators should be selected, especially where it is also necessary to use an iron pin. Porcelain has been greatly improved in strength during recent years, and the present method of firing it in the kiln has thoroughly vitrified the body of the insulator, still leaving it tough. For the testing of insulators see pages 74 to 76.

In the saddle form of insulator, shown at *C*, Fig. 238, with butterfly wings, the portion of the insulator where the wire rests should be provided with rounded edges so as not to abrade the wire if there is any movement of the feeder due to temperature changes. The flarings of the petticoat should not be wide enough to allow water to spatter under them from the cross arm, or narrow enough to invite insects to make cocoons and nests in them. Where a flaring petticoat is used, the top of the cross arm may be rounded and the edge of the insulators made helmet-shaped, so that the drip shall fall outside the cross arm, but these considerations are more pertinent in high tension transmission work.

The strength of insulators can be tested as follows: Place two of the regular pins 24 ins. apart in a wooden beam, 4 ins. × 6 ins., and tie down into the top of the side groove of the insulator a ⅝-in. rod of iron 28 ins. long. A strain by a lever that will give a permanent set to this rod should not fracture the insulator. A test should be given for both top and side strains. The method of making this relative strain test is shown in Fig. 239. No copper line can withstand such strains to an insulator as these tests impose. The strain on the copper conductor is a limiting mechanical factor beyond which it is not profitable to increase the strength of the pole line.

The composite insulator, which is formed of a metallic saddle for the feeder and a metallic bushing for the pin, is a form of insulator largely used. These two metallic parts are held together and insulated from each other by insulating

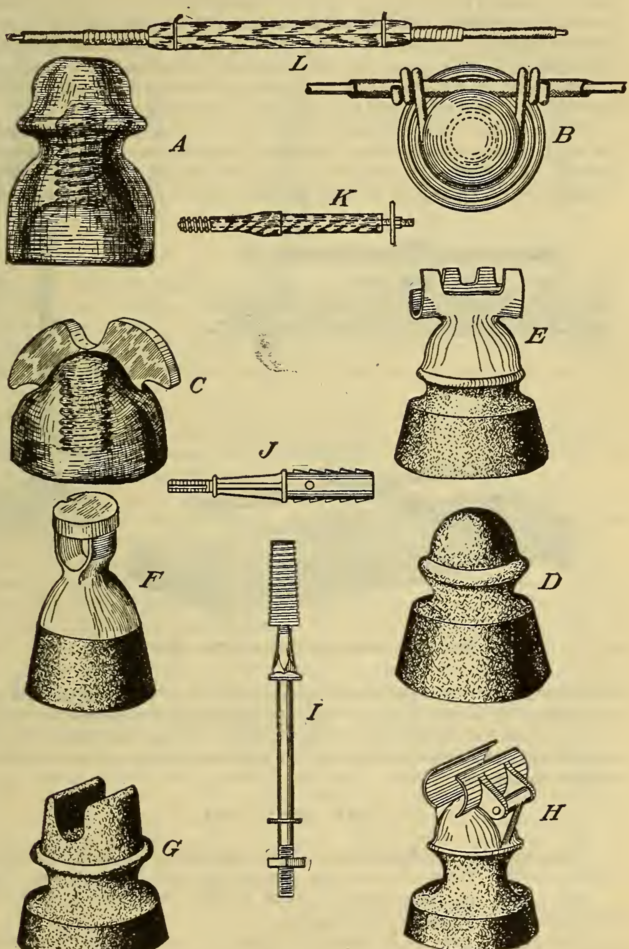


FIG. 238.—LINE INSULATORS.

material which is generally moulded into place under heat and great pressure. The desirable qualities in the composition used are that it have sufficient mechanical strength and that the strength be maintained when the temperature of the insulator has been raised to 150 degs. Fahr. The worst fault of these composite insulators is that they become plastic in warm weather and yield to conductor strains. This composite insulating material should not be affected by rain so if any of the substances in the composition are dissolved, a roughened surface is produced which will hold dirt and cause leakage.

Where the line passes through trees it must be protected from contact with the latter, as the movement of the branches by the wind abrades the insulation of the wire. For cases of this kind the split wooden sheath, shown in *L* in Fig. 238, is often used. This should be held firmly in position so as not to slip along the

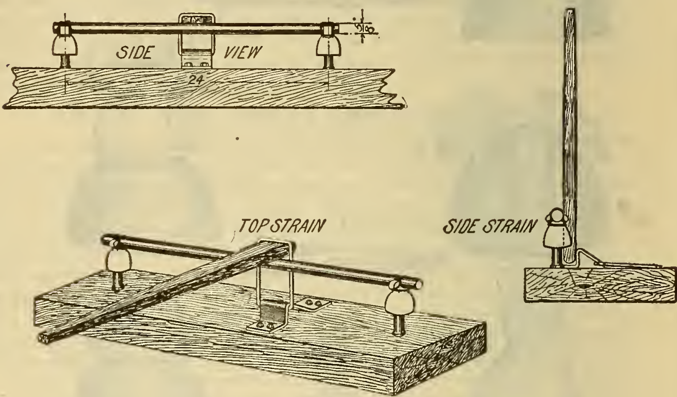


FIG. 239.—METHODS FOR TESTING INSULATORS.

wire, but the really best protection, where it is possible, is to pull the feeder away by guying it to another limb. If a split porcelain insulator is used to enclose the feeder and the guy twisted around the porcelain insulator and some tension put on it to an adjacent limb, the tree and the wire are both free to move without any considerable strain.

THE POLE LINE.

Wooden poles are divided into classes dependent on their form, growth and symmetry. The woods generally used are chestnut, hard pine and cedar.

As a rule, the dimensions of round wooden poles should bear the relations shown in the table on next page.

Cedar poles over 47 ft. long should not be used, as the wind and conductor strains are liable to break them down. All first-class chestnut poles should be second growth—that is, a pole grown from an offshoot of a chestnut tree that has been cut down. This can be determined by the annual rings being larger and of a lighter color, as shown at *A* in Fig. 239, or by the knot holes being nearer the top of the pole. If the bark is on the pole the serrations should not be deep in second growth chestnut.

A pole should be fairly round, and not vary more than 10 per cent. from true diameter all around its surface.

DIMENSIONS OF ROUND WOODEN POLES.

	At Butt.		At Top.	
Length of Pole in Feet.	Cir. in Inches.	Diameter in Inches.	Cir. in Inches,	Diameter in Inches.
30	33	10⅝	18	5¾
35	36	11½	20	6⅜
41	39	12½	23	7⅜
47	44	14	23	7⅜
52	47	15	23	7⅜
57	50	16	23	7⅜
68	53	16⅞	23	7⅜
73	56	17⅞	23	7⅝
84	64	20⅜	25	8

In order that the pole line have a neat appearance, the poles must be straight; no deflection greater than 4 per cent should be allowed from the center line. A pole should be cut down when the sap is not running, either in midwinter or summer, in order to give the best life, as the sap contains the elements that decompose and start dry and wet rot.

After the pole is cut it should be allowed to stand with the bark on it, if exposed to the sun and weather, to season; otherwise it will be sun-checked—that is having cracks which run parallel to the trunk shown at *B*, Fig. 240 and expose the interior of the pole to rot.

A wind-shaken pole, shown at *D*, is one which has been subjected to severe wind storms during growth, which have fractured the fibres thus permanently weakening the pole.

Heart rot in second growth chestnut is generally near or at the butt. If a pole is affected by rot where it is exposed after peeling, internal rot will show on the surface of the pole by dark spots of fungi over the affected parts; when exposed for any length of time fungi will grow on the outside of the pole over the rotten portions. Knot holes larger than ¾ in. within 10 ft. of the butt greatly decrease the strength of the pole, for at this point the greatest strain comes. Knot holes where the core has dropped out or is loose, indicate premature decay in poles. These points are given to indicate what to look for in the selection of first-class poles.

Chestnut deteriorates rapidly when the surface sap wood is cut, and for this reason hard pine is usually employed where special shapes, such as hexagon, octagon, beveled or turned poles, are required. These are not, as a rule, made longer than 40 ft. In the selection of sawed poles the heart should be near the axis of the pole. Wavy grain lines, as at *E*, on a sawed pole indicate that it was sawed from a crooked log, and heavy side strains are very liable to fracture such timber.

Cedar has neither the elasticity nor tensile strength of chestnut or hard pine of the same size, the fracture being a sharp one across the fibre, as shown at *G*, while chestnut still maintains its fibrous fracture when broken, as shown at *F*. Cedar, however, can be secured of very uniform sizes, and in some sections the increased sizes necessary to equal chestnut and hard pine in tensile strength still makes it a cheaper pole.

Iron tubular poles are made up to 50 feet high; both the standard pole and the extra strong poles are made to meet the variation in line strains. Taking one length most commonly used, which is 31 feet, they are usually divided into five classes:

	Lateral strain in lbs. to show 6 in. deflection.	Pounds which will give permanent set of ½ in.
No. 1	350 lbs.	700 lbs.
No. 2	500 "	1000 "
No. 3	700 "	1200 "
No. 4	1000 "	1700 "
No. 5	2000 "	2600 "

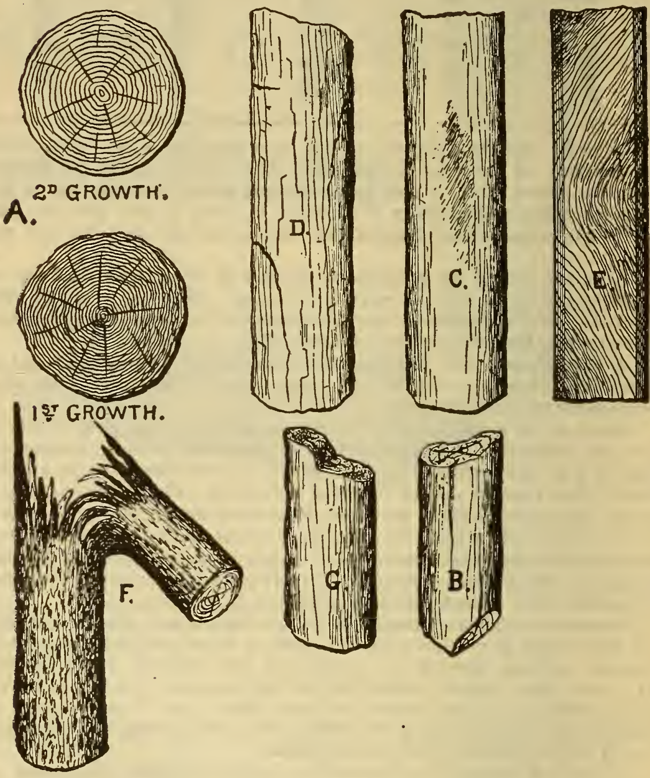


Fig. 240.—Characters of wood for poles.

The test should be made when the pole is set in a proper concrete bed 6 ft. deep and the strain applied to the top of the pole.

The pole should be as nearly round as possible; should not deviate more than ⅛ in. between maximum and minimum diameter, and thickness of tube should not vary more than 1/32-in.; ¼-in. is the greatest deviation that will be allowed from true diameter at the top of the pole. As these poles are made up of sections, some provision should be made to test them where these sections are mechanically connected together. One provision inserted is that the pole should be dropped a distance of 6 ft., butt foremost, on a solid foundation, three times without the joints loosening.

There are two ways of connecting the different lengths, one is by heating the larger pipe, and, while hot, swaging the larger pipe down to the smaller cold pipe, over a length of about four times its diameter; when this joint cools the shrinkage of the outer pipe grips the inner pipe; tests of these joints usually show that they are stronger than either of the single pipes to both compression and lateral strains.

The other method is to introduce between the inner and outer pipe a rusting mixture, usually of sal ammoniac and iron filings; in oxidizing, this mixture increases its volume, thus expanding and making a union between these sections. In testing this class of pipe for deflection the joints sometimes yield and show more permanent deflection than is caused by the pipe alone. These poles are usually constructed by uniting three sections of round pipe.

A guard ring slipped over the pole to rest on the earth at its base has been used, but water is retained here, rusting the pole at the point where it has to bear the greatest strain. These have been removed in a number of cases and the life of the pole prolonged.

The following weights and lengths are usually carried in stock:

27 ft. long,	240 to 350 lbs., standard;	335 to 560 lbs., extra strong.
28 ft. long,	250 to 610 lbs., standard;	345 to 1175 lbs., extra strong.
30 ft. long,	270 to 780 lbs., standard;	375 to 1380 lbs., extra strong.
35 ft. long,	800 to 1050 lbs., standard;	890 to 1670 lbs., extra strong.
40 ft. long,	850 to 1530 lbs., standard;	1335 to 2355 lbs., extra strong.
45 ft. long,	1174 to 1665 lbs., standard;	1835 to 2600 lbs., extra strong.
50 ft. long,	1345 to 1800 lbs., standard;	1995 to 2835 lbs., extra strong.

For pole testing rig see page 73. The results of some pole tests are given below.

Wooden Poles.—

Round bottom.	Top.	Deflection.	Chestnut.	Cedar.
10⅝ in.	5¾ in.	7 in.	340 lbs. to 510 lbs.	360 lbs. to 406 lbs.
11½ "	6⅜ "	7 "	405 " " 680 "	432 " " 540 "
12½ "	7⅜ "	7 "	490 " " 935 "	495 " " 675 "

The above was the average of a number of experiments.

Lattice Poles.—I. Length over all 26 ft. 6 ins., unsupported length 20 ft. 7ins. Laced from butt plate with middle plate.

II. Length over all 28 ft. 6 ins., unsupported length 22 ft. 6 ins. Gusset plates between butt and top plate.

I. Elastic limit 1,540 bs.	Deflection 10 ins.	Pole lattices were filled with cement.
II. " " 3,340 "	" 14 "	

TESTS ON STANDARD IRON TROLLEY POLES.

Nominal Inside Diameter.	Thickness.	Length of Section.		Length of Pole.	Weight.	Deflection at Top of Pole when set in 5 feet of Ground.				
						500 lbs.	750 lbs.	1000 lbs.	1500 lbs.	2000 lbs.
Ins.	Ins.	Ft.	Ins.	Ft.	Lbs.	Ins.	Ins.	Ins.	Ins.	Ins.
4	No. 4	7	6	......	....	....	......	....	......	......
5	No. 3	9	6	28	450	5	8	10¼	20	......
6	9-32	14	0	......	....	....	......	....	......	......
4	No. 4	8	0	......	....	....	......	....	......	......
5	No. 3	9	0	30	515	5	10	17	26	......
6	9-32	16	0	......	....	....	......	....	......	......

EXTRA IRON HEAVY POLES.

4	11-32	7	6	......	....	....	......	....	......	......
5	3-8	9	6	28	708	9-16	5	7⅛	......	......
6	7-16	14	0	......	....	....	......	....	......	......
5	3-8	8	0	......	....	....	......	....	......	......
6	7-16	9	0	30	1025	....	7¼	8½	......	18
7	7-16	16	0	......	....	....	......	....	......	......
6	7-16	8	0	......	....	....	......	....	......	......
7	7-15	9	0	30	1380	....	......	5⅛	7¼	9½
8	1-2	16	0	......	....	....	......	....	......	......

A selected lot of poles costs more than the run of the stock, yet in ordinary trolley line construction money can be saved by designating exactly how many of each class of pole will be required, the best and most uniform poles being for streets and highways, and the poorer qualities used along the country roads. Corner poles and those required to support extra span strains should be specially listed in the specifications; also stubs and anchors or foundation timbers.

Specifications are varied for every class of line construction, but the usual clauses which relate to the class of pole to be delivered are as follows:

Round poles, first class.

There are to be (——) poles, (——) feet long, with an average butt diameter of (——) in. and an average top diameter of (——) in., to be a gradual taper from the bottom to the top, to have no deflection bend or twist which will give the pole a greater deflection than (——) per cent. from the true axis, that the pole shall be peeled clean of bark and fibre, that sun cracks shall not show on the surface of the pole, neither shall it be wind-shaken or checked; no knots over (——) in. will be passed in this class. The butt shall be sawed square and the top chamfered at an angle of 45 degs., the knots shall be trimmed close, gains for cross arms to be cut —— ins. from the bottom of chamfer, and to be cut — ins. deep and — ins. wide. These poles will all be of —— wood and show no signs of dry or wet rot.

For square sawed poles the specifications vary in this way: The pole shall be (——) in. by (——) in. at butt and (——) in. by (——) in. at the top; shall be planed and chamfered, the heart of the tree shall be central

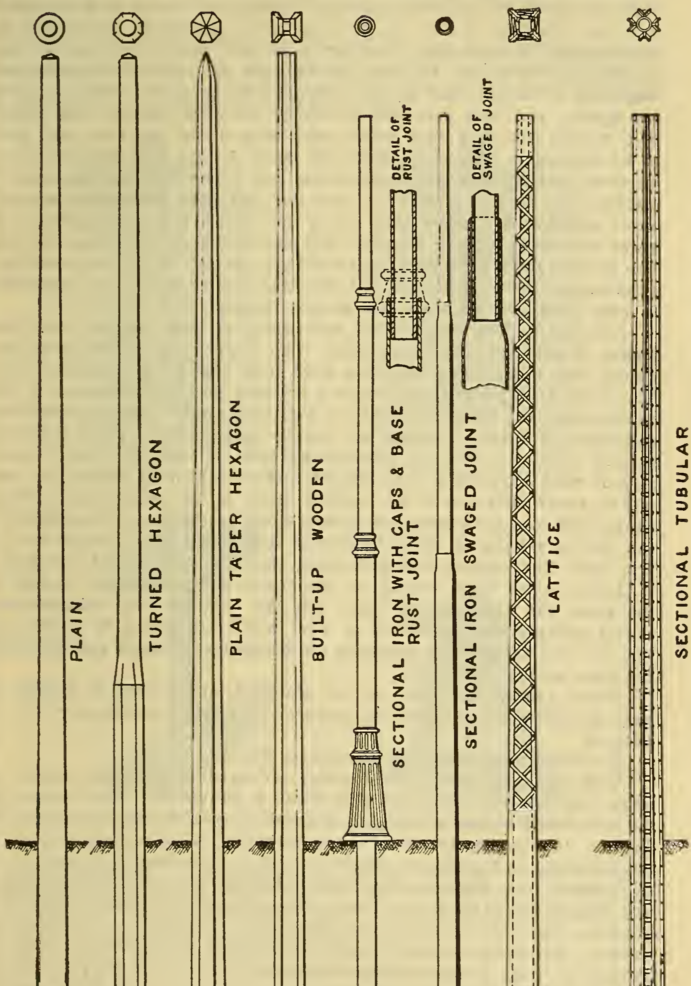


FIG. 241.—TYPES OF POLES.

to the long side of the timber; where this pole is to be beveled on the edge the width of the bevel should be given, also where it is to begin, how far from butt of pole. In hexagon poles the length of the sides of the hexagon, as well as the diameter of the pole, should be given, as also the taper of the poles. In fancy turned poles the height of hexagon and beginning of turned part of poles should also be given. Built-up poles are special, and need drawings to clearly define the design. The length of a wooden pole may vary within such wide limits that sizes will have to be selected to give ample factor of safety for the line strains thrown on them, and depends on the soundness and preservation of the wood to maintain the line in service. A pole that has been thoroughly weather cured standing is stronger than a new pole which is partially green. A green pole shows greater deflection and less tensile strength than one that has been standing some time, so lumbermen do not like to be bound in a specification to the deflection and breaking strains which are applicable to iron poles, and they are not usually inserted.

Iron poles. The weight and dimensions of each section and total length of pole are usually specified. The composition of the metal required may be specified, seamless steel tube now being generally used. The method of putting the sections together may be restricted in the specifications; the tensile strength, as well as the deflection and permanent deflection for different strains, are usually incorporated. To be delivered painted with (——) coats of anti-rusting paint is required; also a turned plug of wood driven in at the butt end, and sometimes at the top, is necessary where they are to be handled much in transportation. Collars, flanges and tops are accessories in most cases on the pole. Manufacturers can drill any holes in the pole without any appreciable advance on the first cost. These poles, with their sizes, should be located and specified.

Lattice poles vary so much in the angles and spacing of the lattice, the slope and character of base, that the contractor or manufacturer should indicate what is desired or what will be furnished by a drawing. The pole can be specified regarding its mechanical strength and deflection the same as the round pole.

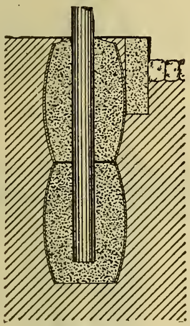
Fancy and special poles are not standard, and cannot be subject to general specifications, unless the product of a single manufacturer is to be adopted.

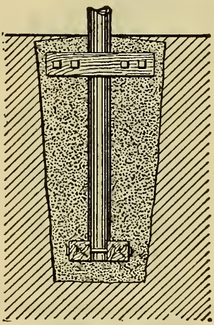
For ordinary shapes and special poles see Fig. 241.

With wooden poles the depth of setting is determined by the line strains, but roughly the pole is set 18 per cent of its length in the ground. For wooden poles the hole should be dug of as small diameter as possible with convenience in digging. In clay ground it should not be larger than 15 ins. at the bottom and 20 ins. at the top. A foot-stone is generally placed at the bottom of the pole on the side opposite from where the strain will fall on the pole. The earth should be well tamped around the pole, and only a few inches of earth should be thrown in at a time. The life of a pole can be considerably prolonged by treating it with creosote. Painting the butt of the pole with pigment, which does not enter the pores of the wood, decreases, rather than increases, the life of the pole. Where sandy ground is encountered, such as will not well support a pole, barrels may be buried one upon another, and the pole set in these barrels, as shown in Fig. 242; where iron poles are to be set in concrete in very sandy soils, the same method can also be used.

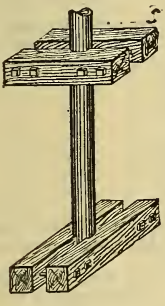
Poles buried in marshy grounds have to be provided with a structure which will increase their bearing areas. Figs. 243, 244, 245 show common methods of these constructions. The support of the pole in soft ground has also to be assisted by head guys or brace studs.

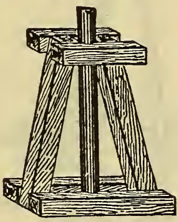
In case of iron poles the surface presented does not give a sufficient bearing area against the soil to carry the strain which the pole is designed to resist, so concrete is used around the base to enlarge the foundation area between the earth and the pole. Fig. 246 shows the standard setting.





FIGS. 242 AND 243.—POLE SETTING IN YIELDING GROUND.





FIGS. 244 AND 245.—SPECIAL POLE FOOTINGS.

The concrete should be composed of one part Portland cement, two parts sharp sand, and four parts broken rock of the size to pass through a 2-inch ring in any direction. The sand and cement should first be thoroughly mixed together while dry, then enough water added to dampen the material and then turned until entirely mixed. The stone is then added and the whole concrete mixed together. Care should be taken that the hole in which the pole is set has fairly smooth sides, so that in tamping the concrete in place dirt will not be knocked down and mixed with the concrete, and so destroy its usefulness. The setting of iron poles in marshy or loose ground requires about the same special structure as shown in Fig. 242.

Where hard stone is met in a few holes only, and in not sufficient quantity to warrant the use of a steam drill or dynamite, a piece of iron pipe slightly larger than the butt of the pole can be filed with teeth at one end, and by rotating this and feeding with emery and water, the hardest rock can be cut to the depth of 4 ft. in a few hours; the core can then be broken out with a chisel. Where concrete is

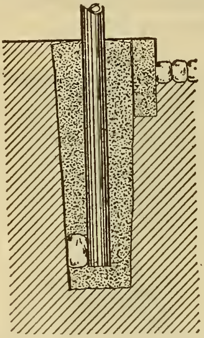


FIG. 246.—IRON POLE SETTING IN CONCRETE.

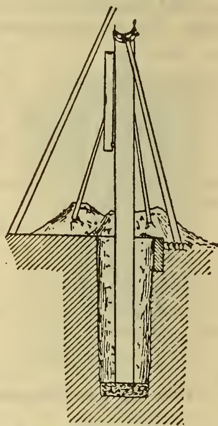


FIG. 248.—METHOD OF SUPPORT FOR TAMPING.

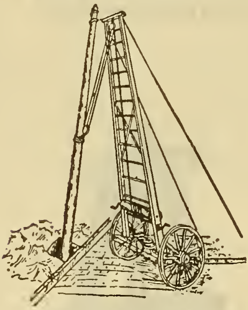


FIG. 247.—METHOD OF RIGGING FOR POLES.

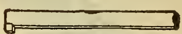


FIG. 249.—LEVEL FOR DETERMINING RAKE.

mixed at one place and carted to the pole line it should be made very wet, and the slow setting variety of cements only should be used. Concrete should always be tamped until a smooth surface shows on the top.

Raising the poles and lowering them into the holes is generally done by a portable derrick mounted on a heavy dray, together with a crab winch (see Fig. 247). This is driven as close to the pole hole as possible—the pole previously being rolled parallel to the road, as close to the hole as convenient, or it can be raised directly from the dray. A chain is rigged around the pole a little above its centre of gravity, and the pole raised up into a vertical position, and the derrick moved over until the pole is directly over the hole. The bottom end of an iron pole should be plugged up flush with a wooden plug at least 6 inches long. The pole is guided down the hole against a skid plank until it rests on the 8 inches of cement and guyed into position, see Fig. 248. The rake of the pole should be from 8 inches to 12 inches, depending on the flexure of the pole and the character of the foundations. A level shown in Fig. 249 is very useful for varying and determining rakes, and by sliding a 1¼ inch projection on one edge of the level any rake can be determined from 7½ inches to 15 inches for a 24 foot pole, and the pole can be set by means of this level. Do not attempt to set the pole by the eye, as a crooked tree or uneven ground will throw the pole out, and it is very important in straight line work to keep the rake the same on all poles in order that the final pole line will pull up nearly straight and present a neat appearance.

The table below gives poles per mile upon different spacings and the weights of line wire they will have to bear.

WEIGHT OF WIRE SUPPORTED BY POLES.

Distance between Centres in Feet.	Poles per Mile.	Approximate Weight of B & S Wire, Weather Proof, Double Braided. Lbs.				
		No. 1.	No. 0.	No. 00	No. 000	No. 0000.
40	132.00	12.9	15.1	18.9	24.2	30.3
50	105.60	16.1	18.9	23.6	30.3	37.8
60	88.00	19.3	22.7	28.4	36.3	45.4
70	75.43	22.6	26.5	33.1	42.4	53.0
80	66.00	25.8	30.3	37.9	48.8	60.6
85	62.11	27.3	32.2	40.3	51.5	64.4
90	58.66	28.9	34.09	42.6	54.5	68.16
95	55.57	30.6	35.9	44.9	57.5	71.8
100	52.80	32.2	37.8	47.3	60.6	75.6
105	50.28	33.8	39.7	49.6	63.6	79.4
110	48.00	35.4	41.7	52.1	66.6	83.4
115	45.91	37.03	43.5	54.4	69.6	87.0
120	44.00	38.7	45.4	56.8	72.7	90.8
125	42.24	40.2	47.3	59.1	75.7	94.6
130	40.61	41.8	49.2	61.5	78.7	98.4
135	39.11	43.4	51.1	63.9	81.8	102.2
140	37.71	45.08	53.03	66.3	84.8	106.0
145	36.41	46.6	54.9	68.6	87.8	109.8
150	35.20	48.3	56.8	71.0	90.9	113,6
160	33.00	51.6	60.6	75.8	96.9	121.2
170	31.06	54.7	64.3	80.4	103.0	128.6
180	29.33	57.9	68.2	85.3	109.1	136.4
190	27.79	61.2	71.9	89.9	115.1	143.8
200	26.40	64.5	75.7	94.6	121.2	151.4
210	24.76	68.6	80.8	101.0	129.2	161.6
220	24.00	70.8	83.3	104.1	133.3	166.64

Pole Fittings.—The standard wooden cross arms usually kept in stock are given in Fig. 250 with the dimensions and spacing for pins. Cross arms are usually kept in white or Norway pine or long leaf yellow pine. The tensile strength of Norway pine is approximately 10,700 lbs. to the sq. in., and the breaking cross load for long leaf yellow pine is 21,300 lbs. to the sq. in. The breaking cross load for the standard size of cross arm is 3820 lbs. for white pine and 5060 lbs. for yellow pine. Records show that the long leaf pine is 40 per cent stronger, but the yellow is more durable, as it does not rot so readily where the iron bolts pierce the cross arm, which is the point

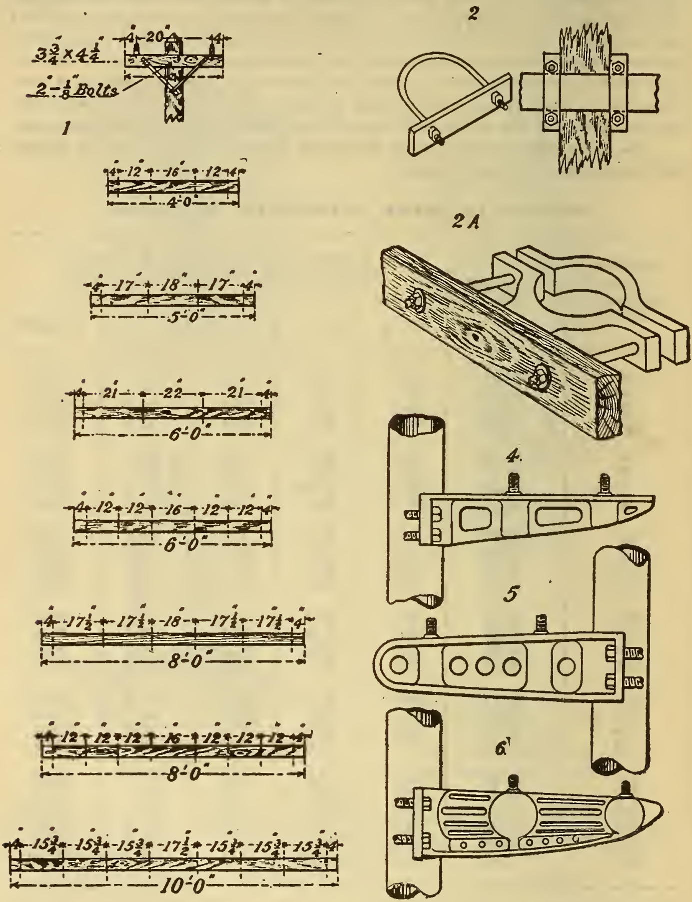


FIG. 250.—MISCELLANEOUS TYPES OF CROSS ARMS.

at which the cross arm has to bear the greatest strain. In order to avoid piercing the wood at this point with wooden poles and also where wooden cross arms are used on iron poles, straps and plates are employed, as shown in Fig. 250. The pole is gained in the regular way when wooden, but

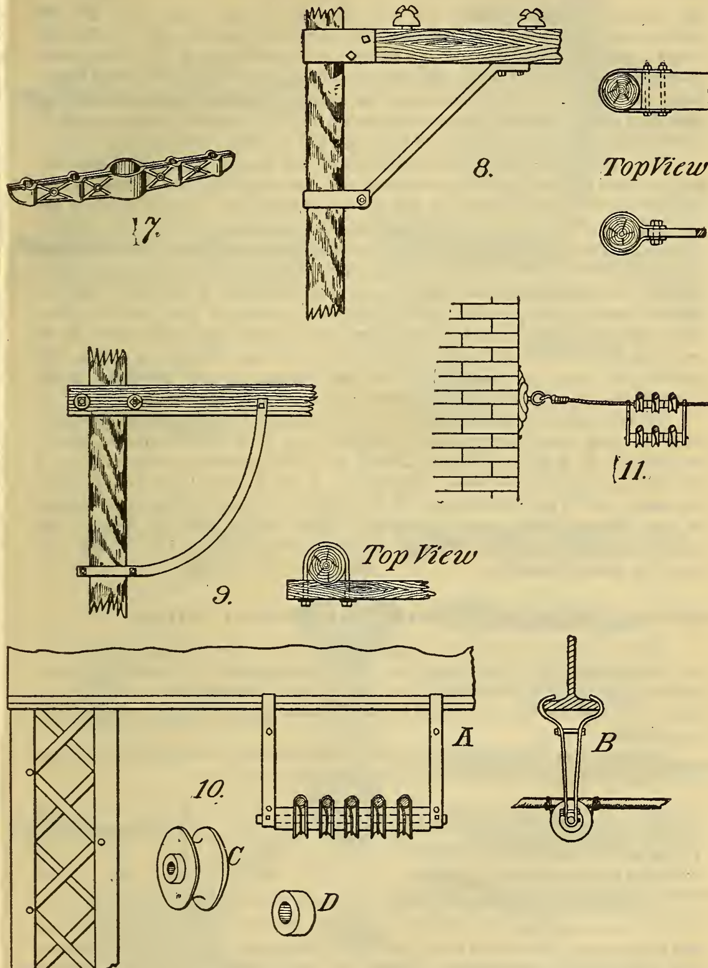


FIG. 251.—FEEDER WIRE SUPPORTS.

where the pole is iron, a saddle is cut into the cross arm to make it fit the pole and thus increase the bearing area of the cross arm. Fig. 250 shows a cast-iron fitting to attach a wooden cross arm to an iron pole. 7, Fig. 251, shows a split cross arm construction where the insulator pin is also the spacing piece between the two halves. For securing cross arms to poles in railroad feeder work, use ⅝-in. galvanized bolts, and lag screws instead of ½-in. Cross arms should be planed straight grained and painted with two coats of Prince's metallic paint, made up in the proportion of 7 lbs. to 1 gal. of pure linseed oil.

Three designs of split cast-iron brackets are shown in Fig. 249. The two halves clamp the pole by two bolts which pull them together; the threads of the top bolt catch the whole strain in this method of fastening. The diameter of the pole at point of connection with cross arms can only vary 1 in. for this style of fastening. Instead of a cast-iron cross arm, a sheet-steel punched cross arm made in two duplicate halves, is shown in Fig. 251. The elasticity of the two halves allows for considerable variation in the size of poles. Four bolts hold the halves together and either iron or wooden insulator pins can be used. Side arms are very useful in dodging trees; where the poles have to be set at a fixed distance from the curb, the arm may be swung either side of the pole, and the feeders in this way cleared of tree contacts. 8 and 9 show the two, three and one pin arm method of fastening.

In some instances the feeders have to be supported on structures. 10 shows them carried under an elevated railroad. At *A* is shown the general arrangement, at *B* the suspension irons, at *C* the porcelain insulator, at *D* the spacing washer between insulators. A ⅜-in. iron pipe threads these insulators, which are placed every 12 ft. to 25 ft. 11 shows how a wire support is made where house connection can be made, but no pole can be set. The feeders are tied in the insulators in this case, and the span wire is also insulated by strain insulators.

ERECTION OF SPAN AND TROLLEY WIRES.

After the poles have been set long enough to have the concrete hardened, or the ground settle, the span wires are strung in position. In some cases guard wires are required, but as a general rule guard wire construction is falling into disfavor, because it has been found to add a greater hazard to the overhead line construction.

The span wire usually employed is of galvanized steel, or Swedish iron, consisting of seven strands, and with general dimensions as follows:

Diameter of each wire in inches	.07	.11	.12	.135
Outside approximate diameter in inches	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$
Weight per 100 ft. in pounds	10	21	29	36
Yards per 100 lbs	307	209	130	88
Breaking strains in pounds average	2500	3950	4600	6100

In some cases No. 1 B. & S. galvanized wiped Swedish iron is used, with No. 0 trolley in short spans, and two No. 1 wires are twisted together for long spans and anchor guys. Stranded span wires give considerable less line maintenance cost, after several years of use. Guard wire spans are No. 8 B. & S. galvanized iron, and for longitudinal guards. No. 10 B. & S. is usually specified. Before erecting the pole it should be provided with the proper gains and holes drilled in them to receive the pole fixtures.

With wooden poles the span wire may be attached to the pole and adjusted by means of an eye bolt, shown at 1 in Fig. 252, or the fork bolt 2, or ratchets 6,

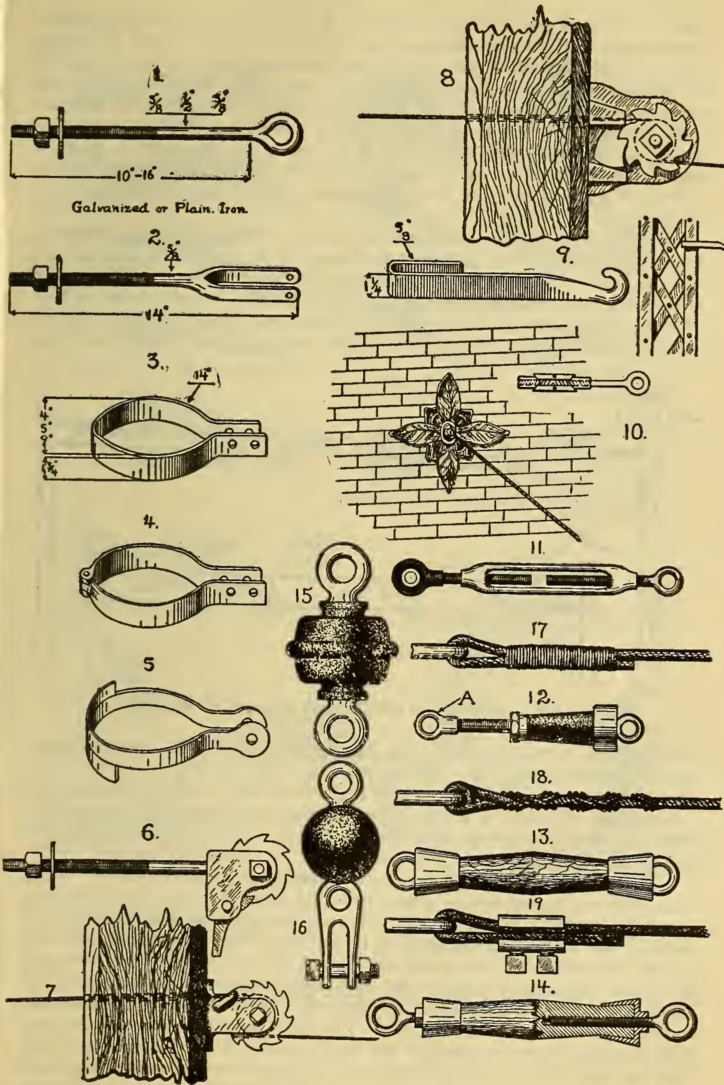


FIG. 252.—POLE SPAN WIRE FIXTURES.

7 and 8, For iron poles, clamps, as shown at 3, 4 or 5, can be used. Where attachment is made to a lattice pole below the pole top, or to a lattice column, the device shown at 9 may be used. Where a wall is used for the support of the span, a rosette and expansion eye bolt, shown at 10, can be employed. Where iron poles are used, turn buckles, shown at 11, are required for taking the slack out of the span wire; sometimes one eye of the turn buckle is insulated to reinforce the trolley insulator. Insulated turn buckles are shown at 12 and 14. At 13 is shown a wooden strain insulator. At 17, 18 and 19 are shown different methods of splicing in the span wire to the eye of the pole fixtures. Nos. 15 and 16 show span wire insulators.

The general methods of disposition of labor in active construction of trolley line work varies in nearly every case, depending on the conditions, material and labor on hand. The work is generally carried out in the following order; placing of pole fixtures, stringing up of the span wires, erection of guard wire, erection of trolley wires, erection of feed wires. When a dead trolley wire is put up it is generally unreeled under the span wires in the middle of the track, and tied with

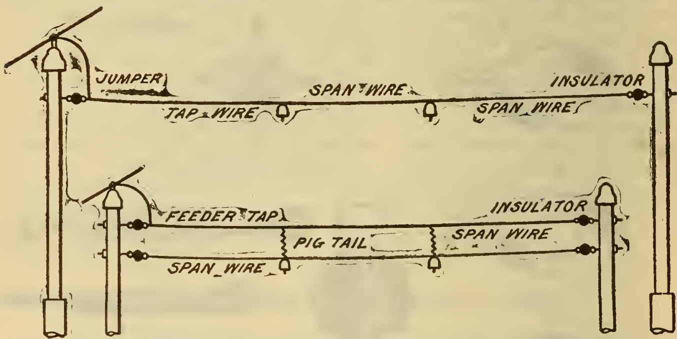


FIG. 253.—METHODS OF CONNECTING FEEDER TO TROLLEY.

temporary tie wires to the span wire, starting the trolley wire from two strain guys; the tension is then brought upon it. To erect a live trolley wire the reel is mounted on a flat car with brake levers and is pushed ahead of the construction car with the trolley under tension, and immediately attached by means of suspension insulators to the span wires. In this way some 6 miles of trolley can be put up in a day.

Where the feeder taps to the trolley wire, two methods are employed: One is to let the feeder tap act also as a span wire, and connect it by a jumper into the feeder ear, as shown in Fig. 253; the other method is to put the feeder ear on a regular iron span wire, and above it stretch the feeder tap, and connect by a pig tail from the feeder tap to the trolley ear. This latter method of construction has several advantages; one is, if the trolley falls, it may break the pig tail, and disconnect itself from the feeder. It also gives a ready method of disconnecting a grounded feeder from the trolley wire. It is found in practice, that a feeder for a span wire has neither the strength nor the durability of the iron span wire, and this weak part of the overhead system can be strengthened by making the feeder tap only an electrical connection, without imposing on it further the carrying of heavy line strains.

FIG. 254.—TROLLEY WIRE INSULATORS AND FITTINGS.

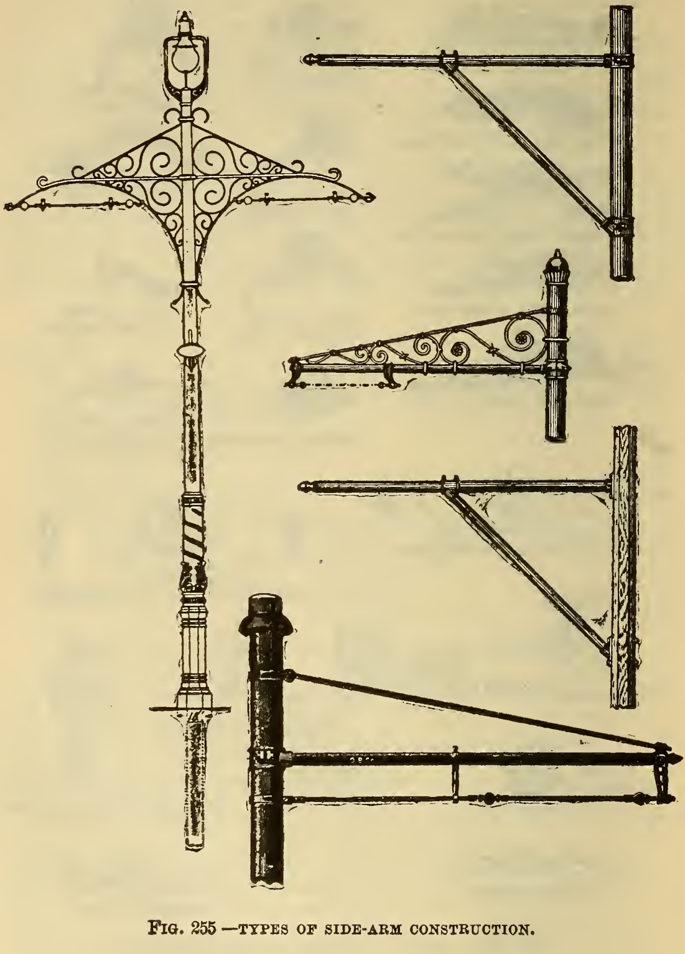


FIG. 255 —TYPES OF SIDE-ARM CONSTRUCTION.

The following strain table will give an approximate idea of the strain on wires when erected for span wires. This table gives the distance of span in feet and the dip of the span wire in inches, with a single trolley and a double trolley:

TABLE SHOWING SAG OF SPAN IN INCHES FOR DIFFERENT TENSIONS AND LENGTHS OF SPANS.

Span in Feet.	Strain on Poles in Pounds.									
	D. T. 500 lbs.	S. T. 500 lbs.	D. T. 800 lbs.	S. T. 800 lbs.	D. T. 1000 lbs.	S. T. 1000 lbs.	D. T. 1500 lbs.	S. T. 1500 lbs.	D. T. 2000 lbs.	S. T. 2000 lbs.
40.........	15.4	10.6	9.6	6.5	7.7	5.3	5.1	3.5	3.9	2.7
50.........	20.8	13.6	13.0	8.5	10.4	6.8	6.9	4.5	5.2	3.4
60.........	26.3	16.7	16.4	10.4	13.1	8.3	8.8	5.6	6.6	4.2
70.........	31.9	19.9	19.9	12.4	15.9	9.9	10.6	6.6	8.0	4.9
80.........	37.6	23.2	23.5	14.5	18 8	11.6	12.5	7.7	9.4	5.6
90.........	43.5	26.7	27.2	16.7	21.8	13.4	14.5	8.9	10 9	6.6
100.........	49.5	30.3	30.9	18.9	24.8	15.2	16.5	10.1	12.4	7.6
110.........	55.6	34.0	34.7	21.3	27.8	17.0	18.2	11.3	13.9	8.5
120.........	61.9	37.9	38.7	23.7	30.9	18.9	20.6	12.6	15.5	9.5

In pulling up span wires, the temperature of the air in which the work is done must be considered, for a span pulled up to 1500 lbs. at 10 degs. below zero Fahr., will only give a strain of 350 lbs. at 90 degs. Fahr., yet a $\frac{5}{16}$-in. span wire pulled up with 850 lbs. at 50 degs. Fahr. will reach the breaking strain at 8 degs. Fahr. below zero, providing the pole does not yield. But the result of constructing high tension line constiuction in hot weather is to throw the poles out of alignment. With a trolley wire more attention has to be paid to strains, because the distance over which these strains can be transmitted being greater, they fall directly on the overhead line construction, and the effort to displace the overhead line fixtures by this tension must be taken care of by strain guys.

In order to keep these strains from distorting curve work, strain guys must be placed at the tangent of the curve, adjacent to the curve, in order to relieve the pull offs from any line strains. Copper trolley wire changes its length in each mile, 4¼ ft. for 90 degs. variation of temperature. The right tension to put on a trolley wire is such that the rise and fall are taken up in the dip, and do not move the line fixtures longitudinally. If, for instance, the poles move with a change of temperature, it may be assumed that the line strains are being transmitted unduly. The way to determine whether this is taking place is to throw a long plumb bob line over the span wire and mark on the pavement the position of the span wire in the cool morning, then again at noonday when the sun has thoroughly warmed up the overhead construction. If there is no change in these two positions of the plumb bob with a taut trolley wire it is safe to assume that each span is automatically adjusting itself to temperature changes without causing undue strains on the overhead construction.

Overhead line construction is put up with all degrees of tension, but it does not require very much observation to see that the high tension construction leads to less trolley wheel wear, and the wheel does not leave the trolley at high speeds as readily as with slack overhead construction. Appearances also certainly favor taut lines.

For approximating the strain put on lines by the block and fall, the distance moved by the pulling rope, divided by the distance this pull moves the line under tension, multiplied by the weight applied to the pull, gives the line tension.

The different standard forms of trolley wire insulators are shown in Fig. 254. These fixtures shown hold a round trolley wire, but the ear may be so arranged as to hold a figure 8, or grooved trolley wire.

Side-Arm Construction.—To decrease line cost and pole obstructions, side-arm construction is often resorted to. Fig. 255 shows some of the types used. The trolley wire fixtures for bracket suspension shown in Fig. 254 are used for securing the trolley wire to the side-arm or bracket and insulating it therefrom.

CURVE CONSTRUCTION.

Overhead work on curves should be so designed that the wheel will not leave the trolley wire in going around the curves. This is practically accomplished when the following precautions are observed:

First. All line tensions should be taken off the trolley wire at the end of both tangents to the curve by running strain wires to take up this tension, (2, Fig. 256.)

Second. The location of the curve of the trolley wire should not be directly over the center of the track except at points of tangency, but should depart from these points toward the center of the curve, the departure being greatest at the last named point. (1, Fig. 256.) The amount of departure at the center increases as the radius of the curve decreases. The table on page 300 shows what this should be for different radii.

Third. Radii of the curves should not be less than 40 ft. Where curves as small as this must be used, an improvement can be made by making the switches at the ends of the curves of a greater radius than the main part of the curve such as using 70 ft. radius at switches on 40 ft. curves; this eases the curve for about 10 ft. at each end depending upon the position of track and center of trolley stand. The proper position of trolley wire around curves can be found by marking the center of stand on outline of celluloid car body in the same way as given on page 124 for locating curves.

Fourth. There should be a sufficient number of pull-offs around the curve, so that the deflection of the trolley wire at any one point will not be greater than 10 degs. This is accomplished by properly spacing the pull-offs for curves of different radii and also by having long ears bent to radius of curve. The table shows the distance apart the pull-offs should be in order that the angle between the trolley wire and the pull-offs should not tend to throw the trolley wheel from the wire.

In the construction of turnouts no additional poles are necessary as the poles for span wires are sufficient with the large radius of curvature. The pull-offs are connected with poles midway between the two overhead switches and the poles on the line with overhead switches. There are a number of different methods of attaching the pull-offs and of locating the pull-off poles. In Fig. 256, 2 shows one method. All pull-offs, independent of their arrangement, must be provided with turn-buckles, so that they can be varied in length, thus enabling the trolley to be adjusted to the proper curve. Another method requiring short pull-offs is shown in 4, Fig. 256. The poles are set on opposite sides of the curves and heavy span wires run between them, the pull-offs being adjusted to this wire. In another method, known as the flexible method, the trolley wire is connected to heavy span wires by means of pull-offs, 5, Fig. 256. Here all the pull-offs are arranged at right angles to the trolley so that this method has the advantage of equalizing all the strains on the different pull-offs, thus tending naturally to hold the trolley wire to a curve.

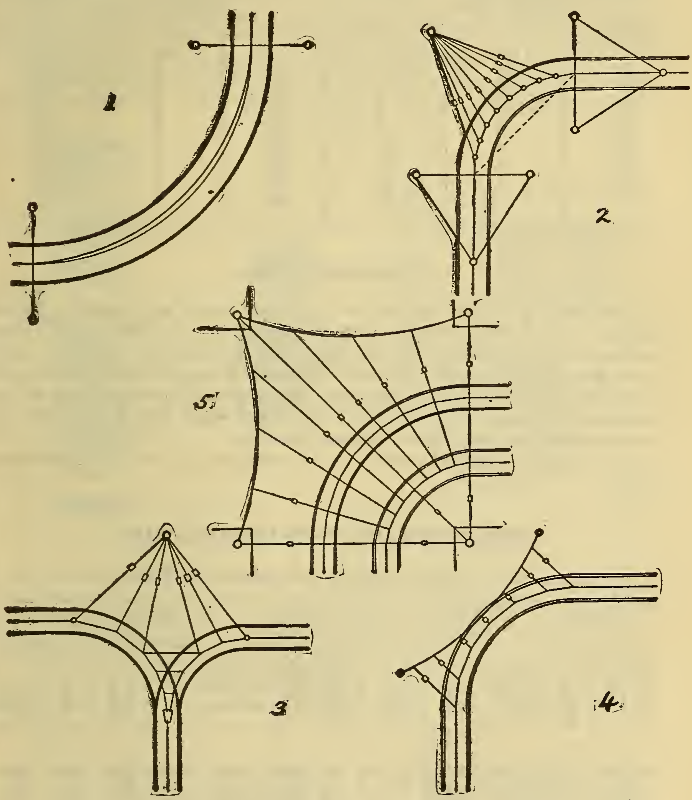


FIG. 256.—CURVE CONSTRUCTION.

When there is a switch in the line, where it branches in the shape of a Y, a general method is shown in 3, Fig. 256, where the pull-off pole is located in line with the switch.

TROLLEY WIRE SUSPENSION ON CURVES.

Radius in Feet.	Distance between Center of Track and Center of Trolley wire.	Distance between Pull-Offs on Curves.	Radius in Feet.	Distance between Center of Track and Center of Trolley wire.	Distance between Pull-Offs on Curves.
	Ins.	Ft.		Ins.	Ft.
35	14	6	100	4	12
40	12	7	120	4	14
45	10	8	140	4	14
50	8	9	160	3	14
55	7	10	180	3	14
60	7	11	200	3	14
70	6	12	250	3	16
80	6	12	300	2	16
90	5	12	350	2	16

TROLLEY WIRE.

This should be hard drawn and in as long length as possible. Several sections besides the round are used as shown in Fig. 257, which leave the lower surface unobstructed for the trolley wheel to roll over. On high speed roads the flashing of the trolley at points of support gives trouble, and equipment breakdowns occur, due to the rise in induced potential caused by this sudden partial rupture of the circuit. The trolley wheel should not strike the insulator bell when worn down to 1¼-ins. diameter.

The tensile strength of round wire, soft and hard, is given in the following table.

PROPERTIES OF SOLID COPPER WIRE.

(B. & S. GAGE. ENGLISH AND METRIC SYSTEMS.)

Gage No.	DIAM.		AREA.			WEIGHT.			BREAKING STRAIN.			
									Hard Drawn		Soft Drawn.	
	Mils.	Milimeters	Circular Mils.	Square Inches.	Square Millimeters	Pounds per 1000 ft.	Pounds per Mile.	Kilograms per Kilometer.	Pounds	Kilograms	Pounds	Kilograms.
0000	460	11.683	211600	.166190	107.20	641	3382	954.30	8310	3768	5650	2562
000	410	10.404	168100	.131793	85.01	509	2687	756.80	6580	2984	4480	2031
00	365	9.266	133225	.104520	67.43	403	2129	600.20	5226	2370	3553	1611
0	325	8.251	105625	.082932	53.47	320	1688	480.40	4558	2067	2818	1277
1	289	7.348	83521	.065733	42.41	253	1335	377.40	3746	1698	2234	1013
2	258	6.544	66564	.052129	33.63	202	1064	299.30	3127	1418	1772	803
3	229	5.827	52441	.041338	26.67	159	838	237.40	2480	1124	1405	637
4	204	5.190	41616	.032784	21.16	126	665	188.30	1967	892	1114	505
5	182	4.621	33124	.025998	16.77	100	529	149.30	1559	707	883	400
6	162	4.115	26244	.020617	13.30	79	419	118.40	1237	561	700	317

No. 0 hard drawn trolley wire is the size usually used for overhead work. The sizes of No. 00 and No. 000 may find favor in high speed work for the purpose of conductors only, but the heavier the trolley wire, the less it yields to the trolley pole springs and the higher will be the rolling contact resistance between the trolley wire and the wheel. Ani ron flanged wheel will cut the tiolley wire badly, and everything in construction should be done to throw the wear on the trolley wheels. The ordinary wear on trolley wire is .001 in. for 65,000 cars, and the natural wear from the trolley wheel would give it a life of about twenty years. The wear is greater on curves and switches than on straight line.

It is bad practice to make a splice in trolley wire by means of a sleeve or coupling close to a fixture. It will be noticed that the trolley wheel in passing a splice

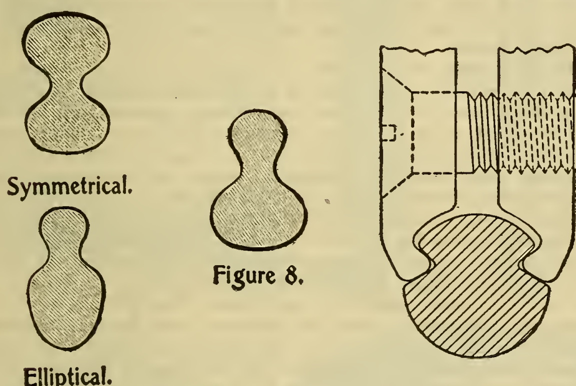


FIG. 257.—SECTIONS OF TROLLEY WIRE.

is slightly thrown from the wire, and if it again strikes the fixture, it will be thrown from the wire considerably, causing arcing at the point where the trolley wire is connected to the fixture. The method of connecting the trolley wires to the ear may be by clamping the ear over the trolley wire, which is soldered to the ear body. The span wires which transmit the strain from the trolley wire to the pole line, should be placed at such intervals that there will not be any considerable displacement of the span wire fixture between the opposite trolley poles. There should be no side strains in case of side-arm construction.

CONNECTION OF GROUND RETURN FEEDERS.

For connecting the ground return feeder to the rails Fig. 258 shows a method where the bond is concealed or not available for attaching a feeder to it. A cast-iron lug is used having the shape shown in 1, A and B. This has a recess cast on its inside surface, a hole diagonal to this recess is drilled just the size of the insulated feeder. The direct connection between the web of the rail and the feeder is effected by inserting the feeder through the diagonal hole and flaring the stranded wire in this recess. The area opposite this recess on the web of the rail and the flaring end of the cable are both amalgamated. A small hole is drilled in the top of the lug entering this recess. After the cable has been inserted and sealed in the lug by means of asphalt paint, and the surface of contact of the lug and rail have been painted with asphalt paint and drawn up tight by means of the two bolts shown, amalgam can be introduced in the recess through this plug hole until the recess is completely filled. In this way an excellent connection can be made between the web of the rail and the feeder. Care must be taken to have the recess tight, by sealing with asphalt paint or varnish.

Where the bond is exposed, have two supplementary feeders running both ways from the feeder tap, as shown in 2, Fig. 258 to cover at least five bonds each way. The bond wire and supplementary feeder should be spliced together by fine wire and soldered. The practice of pouring solder on the joint does not lead to the best results; it is best to use a blow pipe for this work, and to be sure a good solid connection is made. The feeder should be tied between the supplementaries, by a special joint, at least 1 ft. long as shown.

Where a return feeder passes up a wooden pole, it is usually carried inside an iron pipe from at least 10 ft. above the sidewalk to a point adjacent to its connection with its underground supplementary. This pipe must be sealed, so that no water can enter from above along the side of the feeder. Two methods are employed for doing this—concreting at this point, and tamping oakum around the feeder and sealing with asphalt. A 1½-in. pipe is used for feeders up to 500,000 circ. mils. The pipe can be readily bent by packing full of sand and heating.

Where it is intended to carry the return feeders inside iron poles, provision should be made for this arrangement when setting the poles. A hole is drilled and tapped in the side of the pole, about 2 ft. below the sidewalk line, of a size to receive a 1½-in pipe. This pipe is carried to the rails at the point of connection of the feeder with the supplementary. A fish wire can then be run from the opening of the lateral pipe to and up the pole. Sometimes it is necessary to run another fish wire down in order to catch the fish wire through the branch pipe. If the feeder at the top of the pole is connected to the fish wire with a tapering splice, taped with strip lead and slushed with grease, very little trouble will be found in pulling this cable down the pole and out of the side branch. 3 and 4 show these methods of construction.

The return circuit is often grounded by "ground plates" at the station and along the track to assist the track bonding. The improvement of conductivity by such methods is only temporary. The areas these plates present for the ground return are insignificant compared with the areas of rails in contact with the earth, as one mile of 9-in. double track presents 30,000 sq. ft. of contact surface. If ground plates are to be used, they should be of sheet iron ⅛ in. thick and 4 ft. x 4 ft. and buried so deep that they are surrounded by water. If a stratum of rock is found, it is useless to put the ground plate in at all. In case water is struck, about 4 ins. of broken coke should first be tamped down. On this lay the ground plate, which should be provided with a number of bond connections to the ground return feeder. These connections should be well protected by being painted and taped, especially at the point of connection with the iron plate. Above this should be tamped at least 4 ins. more of broken coke, after which the earth thrown in on top and lightly tamped. This construction is shown in 5, Fig. 258.

Ground plates deteriorate very rapidly with use, and a plate of the

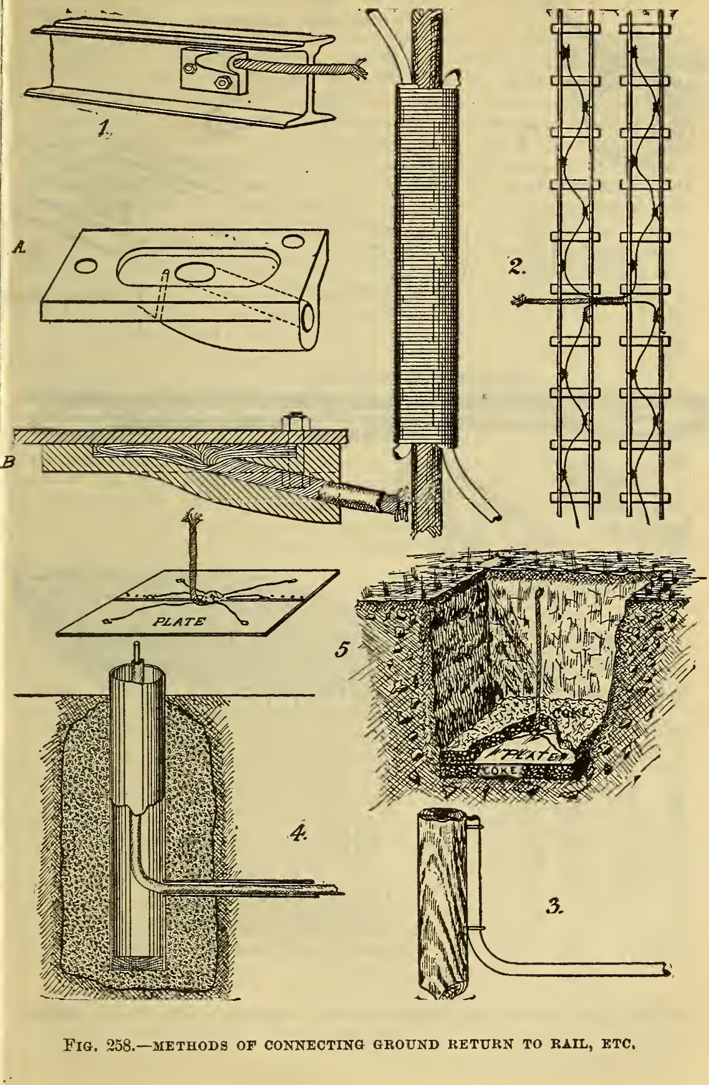


FIG. 258.—METHODS OF CONNECTING GROUND RETURN TO RAIL, ETC.

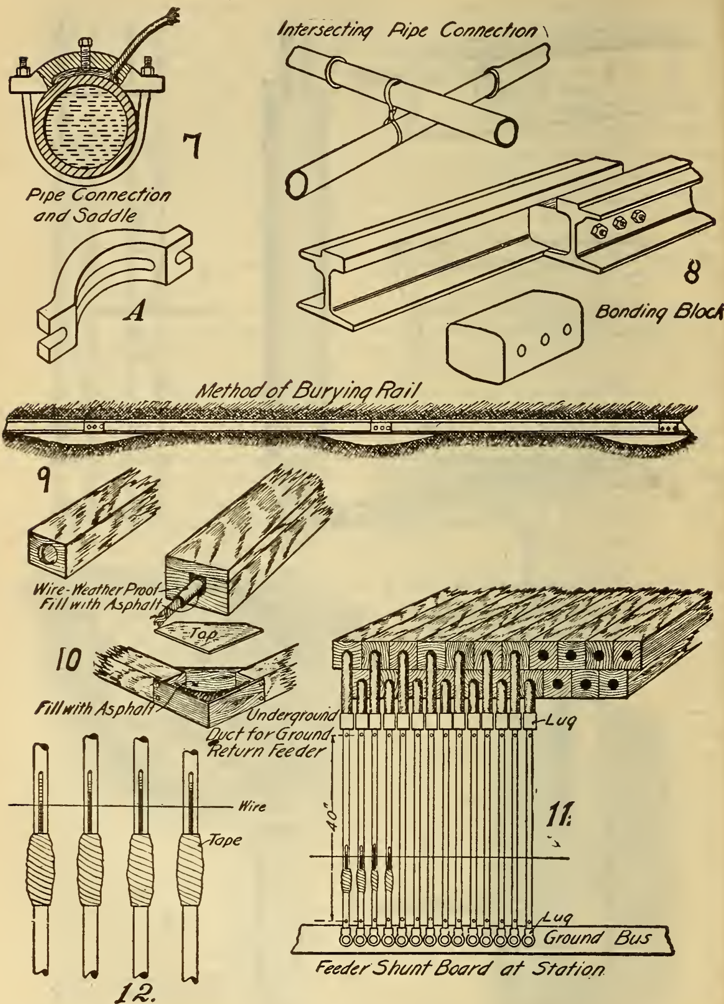


FIG. 259.—GROUND RETURN CONNECTIONS AND METHODS OF MEASURING FEEDER CURRENTS.

size given could not carry more than 25 amps. and remain useful for any length of time.

Fig. 259 shows a method of making connection to a water pipe. A cast iron saddle, shown at *A*, is used, having a recess entering at an angle cast in its contact surface with the pipe. Into this recess is bored a hole which takes the feeder and is a close fit, and into this recess, above where feeders enter, there is a tapped hole for a ⅝-in. bolt. The saddle is secured to the surface of the pipe and the surfaces of contact are fitted fairly closely. The surface of the water pipe, which will be covered by the recess in the saddle, is amalgamated. The surface of contact between the saddle and pipe is painted with asphalt varnish. This saddle is held in position by a strap and nuts. The feeder end is first amalgamated and thrust through the side hole entering into the recess; then the feeder is well painted or calked with jute around the hole which it enters. This recess is now filled with amalgam by means of the hole over the cable shown at 7 forced against the pipe by screwing down on a ⅝-in. bolt, screwed through the tapped hole and against the feeder.

Ground returns have been made by connecting together old rails. The apparently low first cost has been urged in favor of this method of forming ground returns. The method of connecting the rails together to make a continuous conductor has usually been by means of bonds such as used in track construction. 8 shows a method for making the connections without the use of bonds; the rails are lapped and a tinned bonding block of iron, cast to fit the shape of the rails, inserted between them. The contact surfaces on the rails should be well cleaned and ¾-in. bolts used to draw these surfaces together. When these rails are buried, the precaution should be taken to have their bearing surface at the center of the rail. This keeps the rail connections always under compression, due to the weight of rail and the earth covering.

Copper ground return conductors require insulating and will be rapidly eaten away if buried directly in the ground, even if supplied with weatherproof covering. Lead or rubber covered cables are too expensive for this slight difference of potential. These cables can be drawn into a conduit, like that shown at 9 or laid in a grooved moulding, as shown at 10. In these methods of laying, the duct should be sealed with asphalt at all joints and elbows. The grooved moulding is sometimes filled with asphalt and, where a large groove is used, the cable can be supported from the bottom by cleats and the groove filled with concrete imbedding the cable. Caping should not be put on until concrete is thoroughly set.

Where these underground feeders enter the station there should be means for determining whether they are carrying any current or not; to insert an ampere meter in each feeder is too expensive, but if each feeder is run through a copper rod about 45 ins. long (see 11), of such a diameter as to be ample for the largest ground return feeder, and each rod provided with two binding screws located exactly 40 ins. apart on all these rods, these rods can be used as shunts. The current on any feeder can be read when the terminals of the ampere meter are connected to any feeder shunt, the meter being previously calibrated to this size shunt.

Readings taken at regular periods of a week or so will furnish comparative records, and will show exactly what current is being carried on the underground feeders. Where simultaneous, continuous records are required, thermometers can be placed directly in contact with the shunt and taped in place; they should be located near the middle of the shunt and fine wire stretched across the shunts and against the stem of the thermometers as shown at 12. The heights of the mercury in the thermometers are then adjusted to this wire, when the temperature of shunts are the same as the air. When current passes, the rise of the mercury will be as the square of the current flowing, giving a simultaneous visual comparative record of the current returned by each feeder.

The current taken by any ground return feeder, where the contact is rivet bonded, should not exceed 30 amps. per sq.in. of contact surface. With expanded bond this may be increased to 45 amps. per sq. in. and amalgam surface 55 amps. per sq. in. of amalgam contact.

BONDS AND BONDING.

The usefulness of the best bond can be destroyed by not properly applying it. It should never be connected to the rail in wet weather, or where the surfaces are moist. The hole should be freshly reamed before inserting the bond. A special reamer should be used where the bond has a face connection with a mill for the contact surface. The bond before expanding or riveting or forcing should just fit the hole, so no moisture can enter adjacent to the contact. If moisture is present it will gradually work around and corrode the contact surfaces. The channel pin bond gives good results for this reason as the surfaces of contact can be forced into such intimate contact that corrosion cannot work its way between the surfaces.

Fig. 260 shows the West End bond consisting of a taper thimble which slips over the bond wire and secures connection between the bond and rail.

Fig. 261 shows the Johnston bond, which has a thimble that screws on to the bond wire and is clamped to the rail by a nut.

Fig. 262 shows the Bryan bond, which clamps the bond wire by means of a heavy bolt to a contact piece which is forced against the rail by the same bolt.

Fig. 263 shows the Columbia bond, having a thimble which fits the rail tapered to receive a taper bond, which is forced into contact by upsetting the end of the bond.

Fig. 264 shows the Ohio Brass Co's. bond which has a taper split thimble forced between the rail contact and the bond.

Fig. 265 shows the American Solid bond, which makes the connection between the rail and a straight bond wire by a taper thimble expanding a concentric bushing and contracting on the bond.

Fig. 266 shows the American Flexible bond, which secures contact to the rail by a concentric sleeve, in which the bond terminal is expanded.

Fig. 267 shows the Forest City bond, which rivets a large contact surface to the side of the rail by upsetting the end of the bond projecting through the rail.

Fig. 268 shows the Harrington Ball bond, which expands a tubular bond terminal against the rail by forcing graded sizes of balls through the hole in the bond terminal.

Fig. 269 shows the Harrington Diagonal bond, which forces a taper cup, into which the bond wires are brazed, into a hole drilled between the web and base of rail.

Fig. 270 shows the Chicago or Crown bond, which forces the bond terminal against the sides of the bond hole by driving in a taper pin.

Fig. 271 shows the same method of connection but here the bond is sufficiently thin to allow of the fishplate being placed without striking the bond connection. It is called the Crown Protected bond.

FIG. 260.—WEST END BOND.

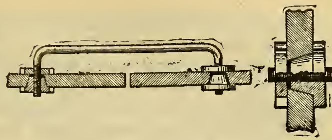


FIG. 261.—JOHNSTON BOND.

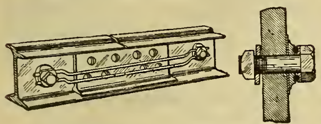


FIG. 262.—BRYAN BOND.

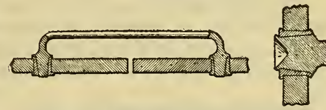


FIG. 263.—COLUMBIA BOND.

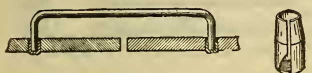


FIG. 264.—OHIO BRASS COMPANY'S BOND.

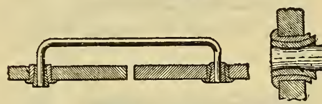


FIG. 265.—AMERICAN SOLID BOND.

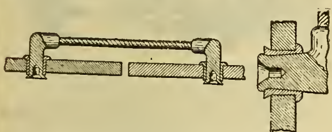


FIG. 266.—AMERICAN FLEXIBLE BOND.

FIG. 267.—FOREST CITY BOND.

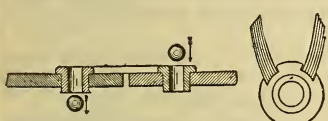


FIG. 268.—HARRINGTON BALL BOND.

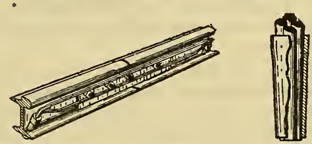


FIG. 269.—HARRINGTON DIAGONAL BOND.

FIG. 270.—CHICAGO OR CROWN BOND.

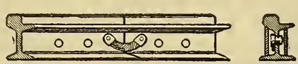


FIG. 271.—CROWN PROTECTED BOND.

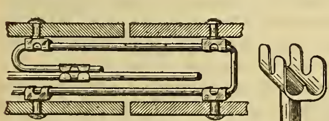


FIG. 272.—GRAUTEN BOND.

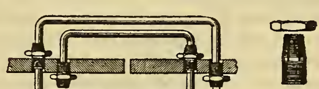


FIG. 273.—STERN & SILVERMAN BOND.

FIG. 274.—BROWN PLASTIC BOND.

FIG. 275.—BROWN BOND FOR OLD RAILS.

Fig. 272 shows the Grauten bond, which consists of a riveted terminal into which the bond wires are soldered.

Fig. 273 shows the Stern & Silverman bond, where a hollow nipple is drilled into the hole in the rail for bonding, and a nut is forced upon a tapering thread which locks the nipple and by compression makes contact with the bond wire.

Fig. 274 shows the Brown Plastic bond, which by a plastic alloy connects the fishplate around the rails it secures.

Fig. 275 shows the same type of bond, where the fishplate is connected to the base of the rail. It is used on rails already laid.

Fig. 276 shows the Payne Welded bond, which can be placed under the fishplate and directly welded to the rail on each side of the joint.

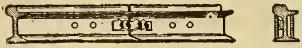


FIG. 276.—PAYNE WELDED BOND.

FIG. 277.—ATKINSON BOND.

FIG. 278.—SYRACUSE BOND.

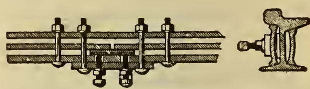


FIG. 279.—AJAX BOND.

Fig. 277 shows the Atkinson bond, which is expanded into contact with the rail hole by pressure.

Fig. 278 shows the Syracuse bond, which is soldered in contact with the rail by use of the proper soldering solution and a special torch to produce the required temperature.

Fig. 279 shows the Ajax bond, which consists of a copper strip placed underneath the fishplate and forced against the rail by screws. The fishplate, the rail web and copper are amalgamated before being put in place.

The table on page 309 gives the results of a series of tests on different rail bonds. Tests by the same engineer, W. E. Harrington, give the cast weld joint, made by Wm. Wharton, Jr. & Co., as 30 per cent of the conductivity of the solid rail. P. Dawson's tests show the resistance of the Falk cast joints to be from 74 per cent to 103 per cent of the conductivity of the same length of continuous rail.

Pressure plays a larger part in the conductivity of a contact than area. In connecting copper to iron there will be present a resistance at the contact surfaces, even if these surfaces are molecularly combined. The Peltier and thermo-electric effects applied to this connection are confused, generally speaking, with the resistance offered to the current of electricity when passing between two conductors of dissimilar molecular characteristics. The aggregate of these effects is practically negligible for the reason that when a current passes from the iron to the copper, the effect will be neutralized by the passage of the current out of the bond again to the iron. Neither the Peltier nor thermo-electric effect are rectilinear functions of the current density on contact surfaces, yet all bond tests exhibit a rectilinear relation between the density of contact and resistance. These effects are, therefore, practically negligible.

It is a question whether drilling a bond hole with oil increases or decreases the resistance, the results of tests showing too great a variation to decide. Amalgamating the end of the bond before riveting or expanding improves the contact resistance, but no brass terminal should be thus treated. To tin a bond where exposed

TESTS ON VARIOUS RAIL BONDS.

W. E. HARRINGTON.

Rail.	Kind of Bond.	C. to C. of Milli-voltmeter Contacts.	Center to Center of Bond Contacts.	Length of Bond.	Size of Contact.	Size of Bond B. & S. Gage.	Number of Wires in Bond.	Ohms.
Penna. Steel Co. 7″ Girder Rail No. 238	Joint only, no bond	36″	36″					.00071
	Iron channel pin	36″	45″	48″	9/16″ pin	0	1	.00049
	Bryan iron wire	36″	36″	39″	Plate 2¾″ dia. 1″ hole in it	½″	2	.000286
	Crown	36″	30″	36″	⅞″ head	0000	1	.000247
	Bryan iron wire, amalgamated	36″	36″	39″	Plate 2¾″ dia. 1″ hole in it	½″	2	.000224
	Crown, amalgam'd	36″	30″	36″	⅞″ head	0000	1	.000185
	Bryan copper wire	36″	36″	39″	Plate 2¾″ dia. 1″ hole in it	0000	2	.000175
	Columbia	36″	30″	36″	⅞″ head	0000	1	.000131
	Columbia, amalga.	36″	30″	36″	⅞″ head	0000	1	.000126
	Stranded crown	36″	5″	7″	⅞″ head	0000	1	.0001
	Plastic socket	36″	3½″					.000093
	Bryan copperwire, amalgamated	36″	36″	39″	Plate 2¾″ dia. 1″ hole in it	0000		.000071
	Plastic cork	36″	9″		Surface 1¼″			.00006
	Ajax bond	24″	24″	8½″	8½ sq. ins.	¼ sq. in. section		.000041
	Solid rail, no joint	24″	24″					.000024
No. 55 Wharton	Joint only, no bond	24″	24″					.0015
	Ajax bond	24″	24″					.000048
	Solid rail, no joint	24″	24″					.000035
60 lb. T.	Double Ajax	24″	30″					.00004
	Solid rail, no joint	24″	30″					.000035
35 lb. T.	Ajax bond	24″	24″					.000051
	Solid rail, no joint	24″	24″					.000044
9″ P.S.Co. Sec. 200	Ajax bond	24″	24″	5¾″	5¾″ sq. ins.	⅜ sq. in. section		.000031
	Solid rail	24″	24″					.0002

to the earth increases its life. A supplementary bond wire is inadequate to assist the carrying capacity of the rail. The same cost in copper and labor at the joint will give a great deal better results. The size of bonds on a railway should be decreased as the current flow decreases. A No. 00 bond should not be required to carry over 120 amps. or a No. 0000 bond, 200 amps., if the contact density at actual contact surfaces is not over 140 amps. per sq. in. The only way to educate trackmen to make proper electrical connections is to test after them by some of the methods shown on pages 39, 40 and 41, or by use of the Conant bond testing method. The best way to attain good bond connection in construction work especially with bonds under the fishplate, is to pay for the work done by a merit system, based on the conductivity of the work; all bonds below a fixed standard to be replaced free of charge.

ELECTROLYSIS.

The decomposition of the iron of the rails or subterranean piping systems due to the flow of current from the metallic surfaces into the adjacent moist soil is known in street railway work as electrolysis. The constituents of the soil may cause corrosion, due to the chemical affinity between soluble matters in the soil and iron, forming an iron rust of several molecular combinations of oxygen and iron. This action may be accentuated by the flow of current from the iron surfaces into the surrounding moisture; but the results of this action are not distinguishable by any visual or microscopical examination over that caused by natural oxidation of these buried structures. Soils high in chlorides will carry this rust

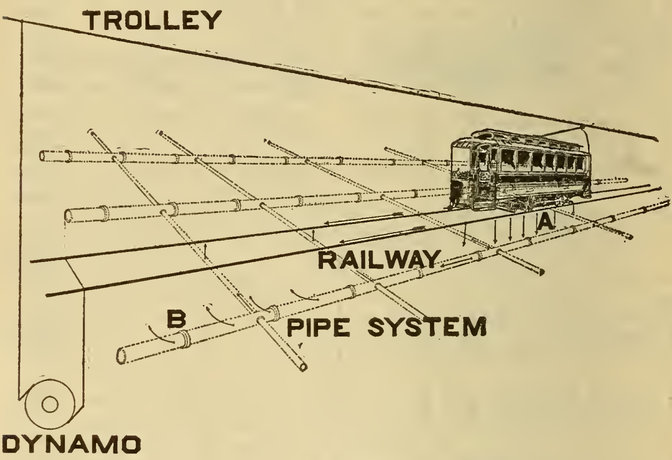


FIG. 280.—GENERAL DISTRIBUTION OF CURRENT.

through adjacent soil. There is, however, a chemical test that can be made immediately after uncovering a badly oxidized pipe, which will in some cases determine whether the cause of depreciation was due to natural oxidation or electrolysis from escaping currents.

In undertaking to determine whether subterranean metallic structures are affected by the rail return current, it is necessary to find the current flow in this structure, and not to base the deductions on potential measurements between the subterranean structures and the rail. Tests given on pages 43, 44 and 45 give data from which the current flow can be determined, and by carefully tracing this current flow along the pipe system its entrance and exit from the pipes can be determined. It has been found in some railways that the current is carried directly into the water pipe system by a portion of the subterranean metallic structure being brought into actual contact with the rails. Such connections should be removed before considering any of the methods for testing. The relations of the water-pipe system to the railway system in regard to the pumping station and main arteries of the water-pipe system and the location of the rails and power station are most important features of the problem and should be carefully plotted out, as well as the current flow in the pipe system laid out by means of ordinates on different parts of the piping system, the ordinates corresponding in length to the current intensity in the piping system. From this data can be ascertained at what point of the piping system the leakage current can be drained away so as to produce the least flow in the piping system, and to reduce the electrolysis of the rails and pipes to the least possible value.

The custom of connecting the pipe system at the station directly to the negative bus-bar rarely leads to satisfactory results. There will be points in the

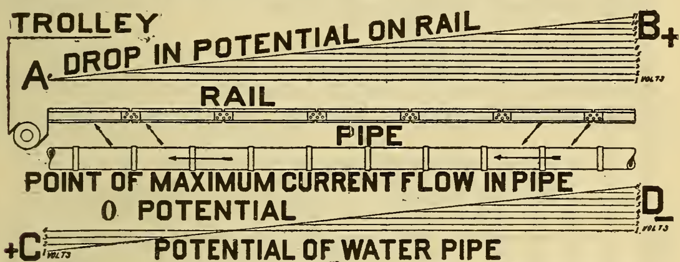


FIG. 281.—DISTRIBUTION OF POTENTIAL: NO CONNECTION BETWEEN PIPE AND RAIL.

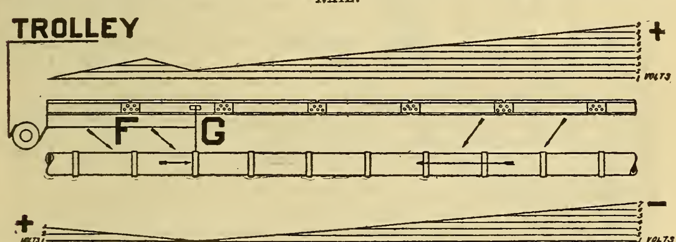


FIG. 282.—CHANGES IN DISTRIBUTION OF POTENTIAL WHEN PIPE AND RAIL ARE CONNECTED.

piping system where the flow of current is maximum, and there is a varying tendency for the current to flow to and from the rails and pipes. If the piping system is tapped at this point and current led away from the railway system and earth resistance interposed between the rails and piping system, this flow will not be found to be large. It should not exceed 8 per cent of the total rail return in any one section.

Fig. 280 shows the general distribution of current between the railway system and the subterranean piping system, and Fig. 281 shows the distribution of potential between these two systems. Between *A* and *B*, Fig. 281, is shown the drop of potential along the rail; between *C* and *D*, the drop of potential on the water

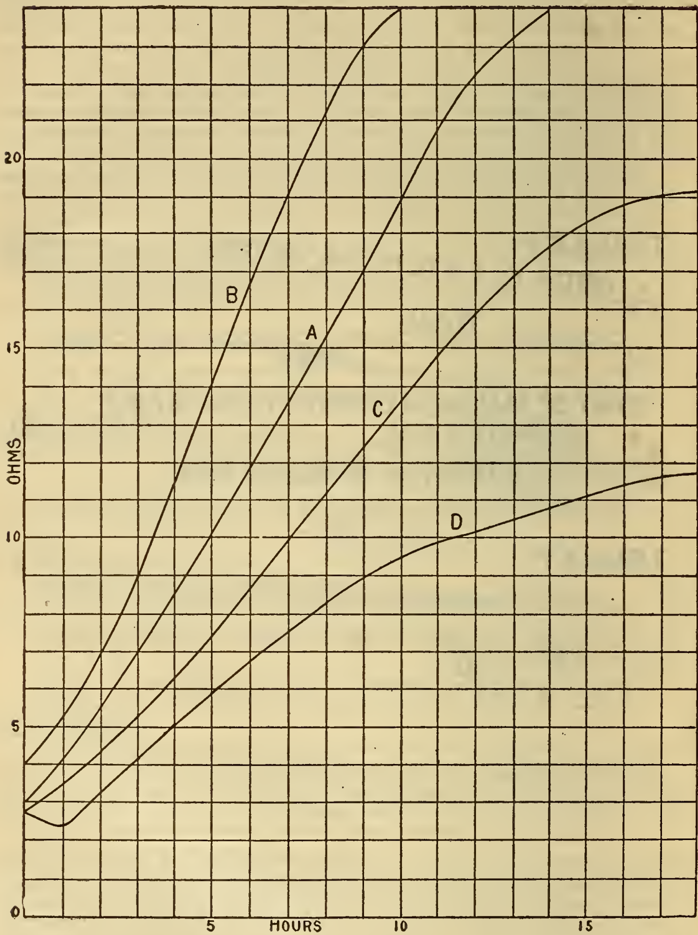


FIG. 283.—CURVES SHOWING INCREASING RESISTANCE OF DIFFERENT SOILS WITH 20 AMPERES PER SQUARE YARD CURRENT DENSITY.

pipe. Fig. 282 shows the change in potential when a connection is made between the water-pipe and rail and ground return feeder.

Tests on pages 44 to 46 will show whether the bond is faulty, and deflecting the current into the water-pipe system. Other methods for more complicated systems have to be used for the reduction of this current flow in the water-pipe systems. Connecting a separate set of feeders to the water pipe at their maximum current flow points, and maintaining its potential at this point above the rail potential, by a separate booster, will tend to dam back the flow of current from the rails. This booster sometimes is compounded by the flow of the main circuit around its fields, so the difference of potential will automatically vary with the output required on the system. Where gate boxes are brought in actual contact with the rails, the iron vertical portion of the gate boxes should be substituted by wood or terra cotta pipe, and no metal portion of the water-pipe system should be allowed to come within 36 ins. of the rails, unless insulated.

The problem of deducing the electrolytic effect on the water-pipe systems, where it is of any consequence, is very complicated, on account of the inter-relations between the two systems and the complex current distribution. It is always possible, however, to find simple means for reducing the current flow in the water pipes to a negligible quantity.

Electrical Resistance of Earths.

Clay, 6 per cent moisture	50	ohms per cu. yd.
Sand, 8½ per cent moisture	35	" " "
Loam saturated with salt water	20	" " "
Gravel and loam, 3½ per cent moisture	87	" " "
Dry Sand	23,000	" " "
Cement, Portland	1,800	" " "
Asphalt, Barber paving	37,800	" " "
Wooden ties, oak rail 3 in. from earth, damp.	8,600	" " sq. ft. rail contact
Wooden ties, dry	18,700	" " " contact

The resistance between a pipe surface and earth rises as the rust accumulates on the pipe. Different soils show considerable variation in these changes, depending upon the soluble constituents in the soil. Fig. 283 shows these variations in a few cases with a current density of 20 amps. per sq. yd.: *A*, soil from Broadway, New York City; *B*, soil from Brooklyn, N. Y.; *C*, soil from Paterson, N. J.; *D*, soil from Peoria, Ill. Increasing the current density causes the resistance to rise and tends to cut down the current flow.

Service pipes passing under the rails in the vicinity of the power station often show the effects of electrolysis, on account of the high current density which the adjacent rail surface focuses on these points. Insulated service pipes made for this purpose should be used in these locations; but if iron pipes are used they should be enclosed in wooden troughs and surrounded by hot asphalt under the rails and for a distance extending ft. beyond the rails on both sides of the track.

SECTION VI.—CAR HOUSE.

In order to design the maximum available storage capacity for a certain area, cut out a plan of a car to a convenient scale allowing the clearance space required on the sides of the car. Where internal pillars are used for supporting trusses, greater distance is required between tracks for clearance. The greatest distance is generally found with open cars with the running boards down, where there should be at least 8 ins. between the running board and pillar. A number of such templets covering the space and clearances required by the type of car to be housed can be arranged in various ways over a plan of the property on the same scale in order to determine the maximum storage capacity with the least special track work.

The width of the property available will determine the economical length of span and support of roof. Wooden roof trusses are advised as decreasing the fire hazard, as the structural iron trusses collapse and prevent fighting the fire from outside. The distance between the car house front and the main track should be sufficient to make the entrance curves outside the car house of moderate radius. For layout of car house tracks, see Page 136.

Transfer Tables.—For handling the cars within the car house, transfer tables are used for which there are several general methods of construction. In one a shallow transverse pit is constructed, wide enough to accomodate, with 18 ins. to spare on each side, the largest single or double truck equipment. The transfer table carries on it a track, upon which, when aligned with any fixed track, a car can be moved. The transfer table can then convey the car to any other desired track. Where the transfer table runs through the middle of the car house, it also forms a bridge to pass over the transfer pit. Another method is to have the transfer table roll on the surface on tracks at right angles to the main tracks. In this case, there are spring sloping tongues which are depressed to the head of the rail, and up which the car rises until it is on the transfer table. This method of construction makes the main track continuous, and the transfer table in this case is only used to transfer the cars at right angles to their length. In case of fire, the latter method has advantages as the cars can be taken out of the car house more expeditiously.

The transfer table can be used in small car houses, and light cars moved by a geared hand winch; or a street railway motor can be geared to the wheels of the transfer truck. The current can be carried to this motor by a trolley wire overhead, or a protected third rail which is under the floor, a shoe being used for collecting the current for the motor on the transfer table. The maximum speed is generally 4½ miles per hour, and the motor geared accordingly.

Overhead Construction.—The overhead trolley may be strung up on span wires as in outdoor construction or under the beam, using a fixture like that

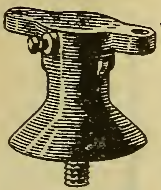


FIG. 284.—TROLLEY FIXTURE FOR INDOOR USE.

shown in Fig. 284. A light T-iron is also sometimes used, insulated from the roof work by blocks of hard wood dipped in insulating paint while the wood is warm. It is important in fixing the height of the trolley wire in the car house to have it so high that the trolley pole tension springs are not under considerable tension, for this weakens them, and makes the trolley liable to leave the wire in service, where the height of the wire in most cases is 22 ft. above the rail head.

Doors.—The car house doors may be either of the swinging or sliding type. The swinging door is most generally used. This door does not require a break in the trolley wire over the sill, if the door is swung both ways from the center. The doors should be well framed and at least 3 ins. thick with double diagonal panelling of yellow pine, and the fastening should be such as to force the door against its jam. Heavy doors should be locked open as well as closed.

Floors.—Car house floors are usually of wood. Wooden block paving set on end has been used successfully. There should in any case be an air space between the floor in the car house and the earth, in order that the hot motors will not sweat badly on cooling over a moist floor. For this reason earth and cement floors, especially where the location of the car house does not afford excellent drainage, should not be used under the equipment where stored. The author has found two cases where high rates of motor depreciation were clearly traced to this cause. Where there is a low track with water standing over it, through which the equipment has to run, several companies place a line of steam pipe between the rails above the floor but clearing the motor, on which steam is kept in wet weather and the equipment thoroughly dried at night. Equipments having low insulation, can be baked in this way.

General Heating.—Where there are inspection pits it is customary to arrange steam piping around the sides of the pits for heating purposes. But for general heating, the indirect heating methods give the best results for a given weight of steam used. Here flues are carried to the different parts of the car house, and heated air distributed. Flues are also located between the tracks with registers so that this warm air can be blown up under the equipment. The air is heated by first passing through a bank of steam pipes, when by means of a blower it is forced through the ducts of the distributing system.

General Lighting.—The lighting of the car house can be best effected by a group of incandescent lamps or enclosed arc lamps which are arranged along the aisles or passage ways. Light for the night inspector should be especially provided, as without proper light his work is only half done, and as no other man can render such valuable assistance in the maintenance of the equipmeut, every convenience should be placed at his hand. In respect to the proper light to work by there have been several satisfactory methods used. One is to have a flexible cord with a 32 c.p. lamp on one end, and a plug at the other end, plug receptacles being placed around the building. A short cord can then reach from the receptacle to the interior or underneath the car, four other lamps being banked together at some convenient location in series so that the trolley circuit can be used. The inspector's lamp should be connected on the "ground" end of the series.

A bicycle lamp arranged with a handle to be carried in the hand also makes a good source of light. For day work windows for side light, and, where the car house is wide, roof light should be provided. Where short roof spans are employed, mill construction with a saw tooth roof having glass on the perpendicular

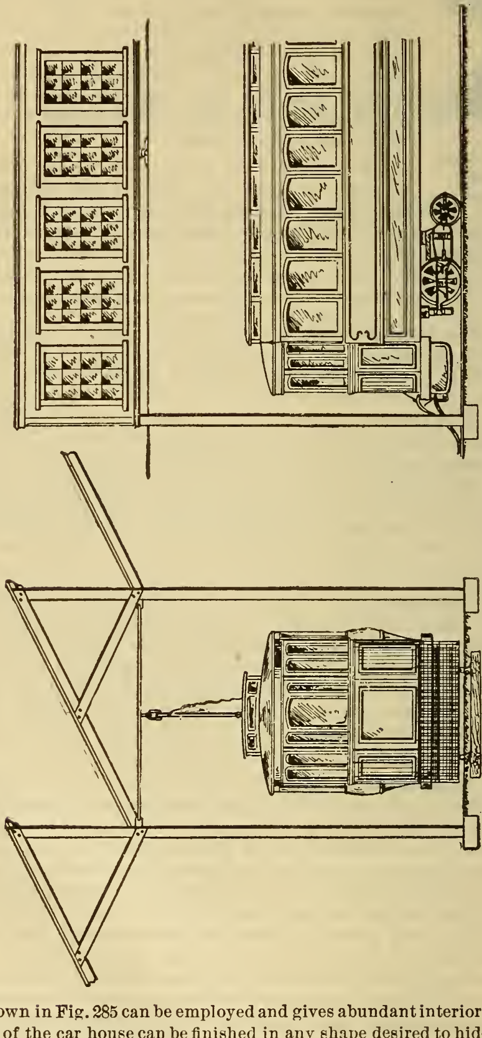


FIG. 285.—A GOOD ROOF CONSTRUCTION.

side as shown in Fig. 285 can be employed and gives abundant interior illumination. The front of the car house can be finished in any shape desired to hide the serrated roof, This method makes one of the cheapest forms of car house structures, where wood is employed. The result of dark car houses is dirty cars and greasy floors with scrap heaps at every available corner.

CARE OF CARS.

Washing.—Where this is done in the car house, a track is generally designated for the work; it should have a cement or asphalt floor pitched ⅛ in. to the foot so as to be well drained. The car is first washed down with a stream of water from a hose. For cleansing the inside floors and seats and sweeping out, compressed air is used with success, as well as for blowing out the interior of the motor and controller. There is no better method to quickly cool a hot motor or boxes.

Lubricating Methods.—Grease is generally put into the journal boxes by means of a paddle, by which it is gouged out of a bucket and smeared into the box. The man who does this, if he is not unusually careful, soon has the floor smeared with grease, and this is the beginning of a dirty car house. It is then transferred to tools, workmen and trucks, and the efficiency of a workman is decreased when he has to look like a coal heaver on account of the grease and dirt surrounding him.

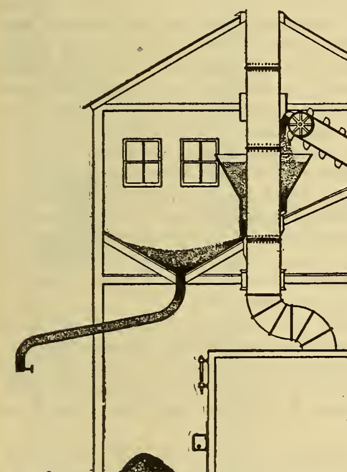


FIG. 286.—METHOD OF DRYING SAND.

The best method is to use a bucket with a short ¾-in. spout soldered to the lower side and a tightly fitting plunger which when screwed down forces the grease out of the spout. This spout can be shoved into the journal box, a turn or two given to the screw and the proper amount of grease injected into the journal box or gear, causing a saving of waste and dirt.

Sand.—This is generally supplied to the cars at the car house. For charging the sanding boxes dry sand only should used and a convenient drying arrangement can be provided as follows: Over the boiler room a sealed loft can be built that is used to heat the house and repair shops. Fig. 286 shows the side elevation of the loft and boiler room. It will be seen that the iron stack from the boiler down stairs passes through this room, and around it is a wrought-iron funnel with a circular opening about 2 ins. wide around the stack at the bottom, and with a flare about 2 ft. wide at the top. The wet sand is introduced into this hopper by a motor-operated conveyor from the sand pile. The sand when dried by the heat of the stack spreads over the flue of the sand bin, and is perfectly dry by the time it reaches the spout whence it is delivered into the sand car. In this way the sand is dried practically automatically, and by heat that would otherwise be wasted.

SECTION VII.—THE REPAIR SHOP.

General Arrangements.—There are several methods in the design of the repair shop by which the equipment can be readily dismantled. In some cases the tracks are elevated from 4 ft. to 6 ft. above the general floor level as they enter by being built upon trestle work with bents about 10 ft. apart. Another method is to locate the repair shop on sloping ground so that the repair shop proper is at a lower level than the car house where the disabled cars are stored. Here the motor and trucks can be lowered to the working floor by some convenient hoisting arrangement. The usual method is to have a pit the width of the tracks or even wider by supporting the tracks by an occasional I-beam, and this pit is generally laid in brick or concrete and made water-tight. In order to handle the motor and take it from underneath the car several devices are used. One is to have a portable horse which can be placed inside the carbody and to which tackle can be rigged to lower the motor into the pit or onto the repair shop floor in the case of a two-story construction. The more modern method is not to place any rigging work inside the carbody but to use a hydraulic jack mounted on a carriage. On the end of the plunger is arranged a cradle which will engage the motor and lower it below the truck parts; this carriage can be run either along a track or the floor and the motors in this way moved where desired.

The tendency in larger repair shops is to raise the carbody off the truck. Fig. 287 shows a rig which will raise the whole carbody well above the truck, so the work can be carried on from above without the use of a pit. The other method is to jack the carbody off the truck by means of four jacks and two cross-beams; after being disconnected the truck is run from under the carbody and carried into the repair shop.

In designing or improving methods of handling car parts in the repair shop, every effort should be made to reduce the time and facilitate the dismantling of a car, so as to remove any of the parts with the least delay possible. With the motor, wheels or any other portions of the equipment many arrangements have been used to carry these parts to the repair department. The sloping track from the pit to the floor of the room can be curved through several pits, or all the pits can lead into one general area-way, so the truck can be hauled up the incline to the repairing floor.

Another method is to have an overhead crane over the equipment, which can carry the parts to the repair shop. Where the overhead trolley is in the way, a long insulated flexible cable is used which can be hooked over the trolley wheel and used to bring in or take out the equipments; this gives clear overhead space for crane work. Another method largely used is an overhead track, made up of two I-beams which are supported by brackets, and on the lower flange between the I-beams rolls the carriage on which the equipment parts are transferred from one part of the shop to the other. Either a differential tackle or air lifts attached to an overhead carrier can be used for raising or lowering the equipment parts.

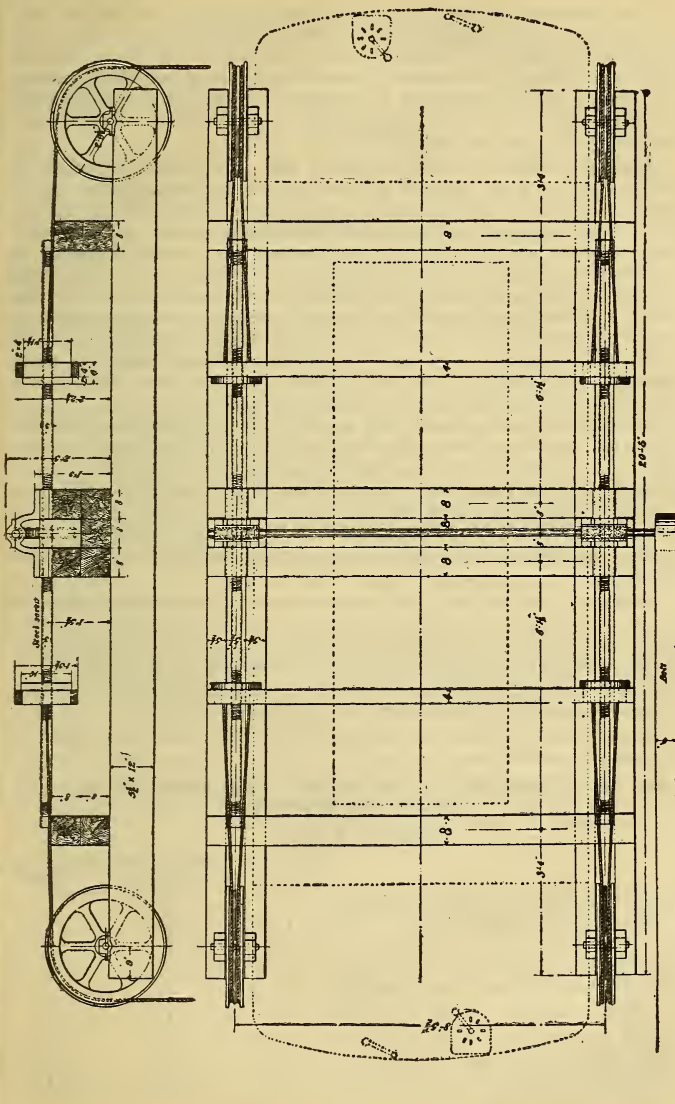


FIG. 287.—CAR BODY HOIST.

The best method to adopt in any repair shop depends entirely upon the relations of the machine and repair shop, and the character of the structures in which this work is carried on. There is still another method for dismantling, practiced by some companies which consists of bolstering up the car body and depressing the track, in this way separating the equipment from the body; then the truck is rolled along the tracking pit at right angles to the car body, and is again raised and carried away from the equipment.

Lathes.—In small shops a screw-cutting lathe with centers high enough to clear the largest motor armature and long enough bed to take a car axle for turning is required. One such lathe for roads operating 30 cars, two for 60 cars, three for 150 cars, should take care of all commutator turning and axle work, even where repairs are heavy. Where an overhead track is used, it should pass over this lathe, so that the work for the lathe can be brought directly to it. It is found in railway repair shops that the heavier types of lathes are required for this work. A grinding attachment is very useful for bringing the bearings to correct dimensions and polishing. With the harder variety of sand stones, commutators could be ground down with less loss than turning. Never use emery wheels on commutators. Tools with individual motors show economy over shafting in machine shop work, and leave room overhead for the crane.

In a small shop a double-gap lathe can be made a universal tool, which will take in the gaps the car wheels and the grinding arrangements fitted to true the wheels. The expense of one tool, where the repair work is light, is less than two lathes, one for axle and armature work, and one for wheel grinding. Where the wheel grinding lathe is used instead of the double-gap lathe for truing car wheels, this should, if possible, be placed away from the other machinery, as the dust and dirt arising from this machine injure the bearings on all the other machinery.

Drills.—An upright drill, with 14 ins. between the center of the bed and post, is a convenient size for the repair shop. Truck frames, structural work, special work and rails can be handled on this drill, as well as line material, controllers, brake rigging and station repairs. In small shops the electric-driven track drill, with flexible shaft, can be attached to an overhead structure and used in the shop for general drilling, when not required on track work.

Planers and Profilers.—Where special work is made up, a planer is required with a 24 in. bed.

LIST OF MACHINERY AND TOOLS REQUIRED IN REPAIR SHOP EQUIPMENT.

MACHINE SHOP.

	SIZE OF ROAD.		
	30-car.	60-car.	300-car.
Speed lathes, 6 ins	1	1	2
Lathes, swing 14 ins. Double-gap swing, 36 ins., screw-cutting	1	2	4
Axle lathe	...	1	2
Wheel grinding lathe	...	1	1
Wheel boring machine	...	...	1
Hydraulic press for wheels and armature pinions	1	1	2
Automatic hack saw	1	1	2
Drill 24 ins. vertical	1	2	4
Planer, 24 ins	...	...	1
Shaper and slotter, 16 ins	...	...	1
Profiler, 14 ins	1	1	1
Automatic tool grinder	1	1	1

ARMATURE AND FIELD REPAIRS.

	SIZE OF ROAD 30-car.	60-car.	300-car.
Armature stands	4	6	12
Field winding machines	1	2	3
Baking ovens	1	1	2
BLACKSMITH SHOP.			
Forges	2	4	6
Drop hammers	...	...	1
Shears, cut ½ in. x 6 ins	...	...	1
Punches, hole 1 in. x ¾ in	...	...	1
WOOD WORKING TOOLS.			
Planer's surface	1	1	1
Splitting saw	1	1	2
Moulders	1	1	1
Joiners	1	1	1
Sandpaper machine	...	1	1
Vertical mortising machine	1	1	1
Tenoning machine	...	1	1
Boring machine	1	1	2

Where there is much brass work done in the shop, such as overhead line material and equipment parts, the profiler certainly gives the greatest and most direct method of finishing these castings, and practically can do any work that a small milling machine can

Other Tools.—The hydraulic press for pressing wheels on and off should also be provided with a device for pressing off the armature pinion and commutator. The armature pinion is often started by a blow from a heavy hammer which in many cases has bent the shaft.

There is no small tool more needed in the repair shop than an automatic hack saw which will save considerable labor. One large enough to take the standard rails should be secured.

Armature Stands.—There are a number of methods of designing armature stands, the most primitive being two horses in which there is a V cut on the top of the back, in which the armature is rotated. A deviation from this plan is to make two A-shaped supports braced together, on the cross-bar of the A being a platform for tools and coils. Instead of a plain V two rolls are often used for the shaft to rest in so that it can be readily turned around. The more modern method of making armature stands is to provide two pedestals secured to the floor, which can be elevated or lowered by means of screws and the armature rotated in a fork on the top of the pedestals. This allows the winder to get right over his armature. At his side is a stand for tools and coils. For winding bands on armatures a handle can be clamped over the pinion or shaft, and the binding wire wound under tension.

Field Winding.—This is often done in some shops on a lathe, speeded at low speed. If this is a screw-cutting lathe with a capacity to give the proper turns per inch for the wire, by clamping the wire in a tension device secured in the tool post, the wire can be laid on automatically by the feed of the lathe, and at the end of the turns, with a little practice, the winder can soon reverse the feed so there will be no lap over.

Where field winding machines are built especially for the purpose, a screw working into a worm gear gives the best results as this locks against any slack, and an automatic arrangement can be attached to the wire feed, consisting of a right and left hand screw which are opposite the side of the field. These screws will rotate one turn for every turn of the field, and the threads per inch are equal to the turns per inch required on the field. The wire is held on the rig... screw in going forward and depressed on the left hand screw in going bac...

Bake Ovens.—Small bake ovens for armatures and fields can be ... the form of a box, into which the armature is slid or the fields hung. T... should have an iron bottom with a number of perforations, and be raise... 6 ins. from the floor. Underneath this perforated iron floor are arranged ... of five lamps, which are enclosed by a false box in the bottom of which ar... a number of holes. This should clear the floor about 2 ins. On the top of ... there should be two rows of ½-in. holes about 4 ins. apart, and a slot slid... over these holes. There are holes in the slide so placed that they will register ... holes on the box; and in this way sufficient ventilation can be produced ... take away the moisture or fumes which are driven from the armatures or field... In a number of cases where bake ovens have not given satisfaction it has bee... that they did not have sufficient ventilation, the air in them becoming so ... that it would take up no further moisture. The temperature of a ba... should not be carried over 180 degs. Fahr., especially if linseed oil is us... insulating medium.

General Remarks.—Where compressed air is used for cleaning t... tures, a pipe can be run to the blacksmith shop. If a small nozzle is int... into the center of the supply pipe, a small jet of compressed air will indu... of air which can be easily regulated and controlled for the forge fires.

The repair shop should be lighted and well ventilated, and where ov... wide, this should be done from the top as well as the sides. To paint th... of the repair shop with cold water white paint gives a neat appeara... increases greatly the interior illumination. The floors can be concrete ... and where pits are in the repair shop the floor space can be increased by ... sliding doors, with handles to slide on battens between the rails. The ... can be slid underneath the truck when only the truck is being worked ... pit should be lighted by side lights which are covered with wire shiel... pits should be slightly sloped towards one end or the middle where a de... can be made in the cement for collecting any seepage or moisture, wh... accumulate in the pit.

It is best to have the pit floored with 2-in. hard pine flooring, laid ... the concrete, which gives a better surface for rolling the trucks and hand... the material. The usual practice in locating machinery in a repair shop ... place it, that the work passes from one part of the shop to the other in it... without passing the same point twice.

It is great economy to have all tools belonging to the company mar... have a tool-room and a workmen's check system, in order that the tool... be replaced, or, if mislaid, the person responsible can be known. In small ... foreman is generally tool-room keeper, and keeps the tools in order, and ... cases an automatic tool grinder is located in the tool-room.

It expedites work for each repair man to have his own set of tools, c... of large and small wrenches, hammers, cold chisels, pliers, calipers a... which are supplied him by the company and charged to his account, cre... given on their return. In repair shops, where the cost of repairs is lar... almost invariably been found that a large amount of time is lost in loc... tools which can be left anywhere on the work-room floor. Poor or ... tools do not lead to the best work and discourage the workmen.

The numerous labor saving tools and wrinkles for the repair of the ... parts of the equipment can be found in their proper place under "Equip...

SECTION VIII.—THE EQUIPMENT.

THE CAR BODY.

Modern practice in car body construction for heavy high speed work is indicated by the specifications given below, which are abstracted from those used by the South Western Missouri Electric Railway, and are for a car body 30 ft. 6 ins. long, with smoking compartment. This type of car body has been selected for standard specifications as it covers all the details required in the most extensive systems.

Whereas the structural woods, which have been selected in this specification, conform to the general nomenclature regarding the kinds of wood to be used, the specific species of wood is not often included in the car body specifications, except that for interior finish. The woods forming the modern structure of the car are specified in a general manner since a specific kind of wood is very often difficult to procure. Furthermore the lumber market to-day does not furnish, in the proper quality and lengths, certain varieties of oak which some years ago were readily procured. The lengthening of the car body has made these long timbers, particularly the sills, difficult to obtain, especially so when a particular species of oak is specified. The tendency for car body construction is to abandon timber for the longitudal beams on the car and to introduce angle iron around the sill, the whole length of the car, to produce the necessary strength. This method also decreases the depth of the sill.

The details are fully designated in the specifications, which form a guide to the general make up and dimensions of the parts entering into car-body construction.

The size of car bodies varies. The dimensions of a number of car bodies, which have been recently ordered, are given for reference in the table on page 324.

Car Body Specifications.—General Dimensions.

	Feet.	Ins.
Length of car body over corner posts	30	6
" " " over vestibules	40	2
" " " " bumpers	41	2
Width of car body at sill, over plates	8	3½
" " " " at belt rails	8	3½
" " " " over water drip rails	8	4½
Height of car body from under side of sills to top of roof, not including trolley board	9	0
Height inside, from floor to top plate	6	3
" " " top of floor to underside of upper deck ceiling...	8	2
" from track to underside of sills when car body is mounted on trucks	3	1

Bottom Framing.—Side sills of very best quality long leaf yellow pine, size 4½ ins. x 7¾ ins. finished, reinforced on the outer sides with steel plates ; plates to be ⅝ in. thick, 7 ins. wide, extending full length of car body and around corners

APPROXIMATE DIMENSIONS OF VARIOUS STYLES OF ELECTRIC CARS.

KIND.	Length over Platforms.	Length over Posts.	Length of Platforms.	Height over all.	Size of Wheels.	Height Inside.	Width.	Number of Seats.	Kind of Seats.	Seating Capacity.
	ft. ins.	ft. ins.	ft. ins.				ft. ins.			
Closed	24	16	4	10 ft. 6 ins. to 11 ft.	33 ins. to 36 ins.	7 ft. 8 ins. to 8 ft.	7 6	2	Length of Car	22
"	26	18	4	"	"	"	" "	2	"	26
"	32	24	4	"	"	"	" "	2	"	34
Convertible summer and winter	33 6	25 6	4	"	"	"	7 10	2	"	40
Combination, open and closed	29	11 8	....	"	"	"	7 6	..	....	open part 24 closed " 16
Open but closed ends	26	20 8	2 8	"	"	"	6 10	8	reversible	40
Open and open ends	22 6	....	....	"	"	"	" "	7	"	35
" " " "	30 9	....	....	"	"	"	7 2	10	"	50

GENERAL DIMENSIONS OF FOUR STANDARD CARS.

ITEMS.	GENERAL DIMENSIONS.			
	No. 1, Brooklyn, Double Truck, Closed Car.	No. 2, Boston, Double Truck, Closed Car.	No. 3, New York, Metropolitan, Single Truck, Open Car.	No. 4, Brooklyn, Double Truck, Open Car.
	ft. ins.	ft. ins.	ft. ins.	ft. ins.
Length over all	34 1¼	33 1	32 8	35 3⅛
" of body	25 0½	25 0	23 2⅝	26 3¼
Width over all	8 0½	7 10½	8 1	8 3
Width at belt rail (closed car) or side posts (open car)	7 9	7 6	7 4½	7 3
Width at sill	7 0	6 8	6 7	6 6
Height over all (bottom of sill to top of trolley board)	9 1	8 9½	8 9¼	9 0
Height, top of floor to bottom of side top rail	6 1	5 7⅞	6 0½	6 0

to door posts on ends in one continuous piece and securely bolted to sills with oval head carriage bolts.

End sills of oak, size 7¾ ins. x 4⅞ ins. finished.

Cross sills of oak, size 6⅞ ins. x 2¾ ins. finished.

Diagonal braces of oak, size 4 ins. x 1¼ ins. finished.

Trap door framing to be arranged to meet the requirements of the........ motor, for two........motors to each car, of type No.........and of........hp. each.

Bottom framing to be also arranged to meet the requirements of the.......... double trucks, with wheels 33 ins. in diameter, wheel base of trucks........., distance between centres of truck bearings........, bolsters to be set back.......... from end of car body, gauge of track 4 ft. 8½ ins.

Bottom framing to be tied together with ⅝ in. round refined-iron rods, one for each through cross sill, extending across the whole width of bottom frame and through side sills and plates, with thread and nut at each end. Short framing and trap door framing to be also tied together with ⅝-in. round refined-iron rods and plated where necessary. Body bolsters to be made of 9 ins. x ⅞ in. and 9 ins. x ⅝ in. iron filled with oak, made to suit the requirements of the trucks and securely bolted to the car body.

Inside truss rods to be made of 2 ins. x 1½ ins. refined iron with 1 in. round ends with thread and nut. These trusses to be placed as high as possible and out into posts and securely fastened to posts and sills. Also truss rods of 1 in. round iron to be placed underneath side sills to support centre of car, with turnbuckle in the centre, and securely bolted to sills at ends.

Floor to be of best quality quarter-sawed yellow pine, ⅞ in. thick with 2½-in. face, tongued and grooved, closely laid longitudinally with car and securely nailed to bottom framing. Floor to be of two thicknesses, the lower layers being laid crosswise and the top floor to be laid longitudinally with car. Trap doors to be fitted with large wrought-iron handles, counter sunk into trap doors and bolted through.

All parts of bottom framing and under side of floor to be painted with brown oxide of iron paint, and all mortises and tenons to be thoroughly white leaded when being put together.

Body Framing.—All posts, rails and other parts of body framing to be of best quality tough ash. Ventilator rails to be faced with oak on the inside and molded. Side of car to be framed for 11 windows on each side with straight siding below windows. Ends of car to be framed for double doors and one window at each side of door opening. Posts to be well braced. Diagonal cross bracing between posts, made of oak ⅞ in. x 3½ ins. and tightly fitted. Outside of car below window to be sheathed with matched poplar sheathing vertically and well nailed to body framing, sheathing to be ¾ in. thick and 2 ins. wide on face.

Inner side of sheathing to be backed with best qualily linen scrim well glued to sheathing, posts and bracing, and when the glue has become hardened the scrim to be painted with brown oxide of iron paint. The joint between sill plate and sheathing to be covered with 1¼ ins. x ¼ in. half oval iron molding extending full length of body at sides, also on ends. The joint between arm and rail and top edge of sheathing to be covered with 1¼ in. x ¼ in. half oval iron molding extending full length of body and around corners to door posts on ends in one continuous piece. Posts to be secured at bottom with strap bolts made of 1¼ in. x $\frac{5}{16}$ in. iron, extending through sill with thread and nut at bottom. Strap bolts to have heel bent on top and cut carefully into posts and to be securely screwed to posts.

Posts to be tenoned, and sills and top plates to be mortised, drawbored and pinned and all pinning to be done in such a manner that pins will draw tenons into mortises.

Tops of posts to be provided with wrought-iron T-plates securely fastened to posts and top rails. Side top rails to be of best quality yellow pine, size 4¾ ins. x 3 ins., finished, strengthened by a heavy letter panel made of ash 1⅛ ins. thick and 7 ins. wide, which is gained into top rail as well as posts. Under drip rail to be 2¼ ins. x 2¼ ins. x ¼ in. angle iron, extending from corner post to corner post in one continuous piece and securely screwed to posts and letter panel. Arm rail of ash, size 1¾ ins. x 4⅛ ins., finished. Side posts of ash, 2¼ ins. thick, cut to pattern. Corner posts of ash, 4 ins. thick, cut to pattern. Diagonal bracing between posts of oak, size ⅞ in. x 3½ ins. Truss plank at bottom, inside, of ash, size 1¼ ins. x 9 ins. Door posts of ash, size 2½ ins. x 2¾ ins. Each door post shall be provided with one ⅜ in. round iron rod, extending from top of head piece through to bottom of end sill, screwed to headpiece and let into door posts, and to have thread and nut at bottom.

Roof.—To be of the monitor-deck pattern full length of car. All parts of roof framing to be of best quality tough ash. Ventilator rails to be faced with oak inside and molded. Lower ventilator rail of ash faced with oak, 2½ ins. x 4½ ins. Upper ventilator rail of ash, size 2¼ ins. x 3¾ ins. Ventilator mullions of ash or oak, size 1⅜ ins. x 2¼ ins. Side of lower deck carlines of ash, size 1⅛ ins. x 2 ins., cut to pattern, glued and tenoned into lower ventilator rail, and shouldered, glued and screwed to side top rail. Centre of upper deck carlines of ash, 1⅛ ins. x 1¾ ins., cut to pattern, glued and screwed to top ventilator rails.

Roof to be further supported by ten steel carlines, one over each intermediate side post, made of 1¼ in. x ⅜ in. steel, forged to shape of roof in one continuous piece and extending from side top rail to side top rail, with a foot at each end, which is securely screwed to side top rails. Steel carlines to be securely bolted to wood carlines. Roof framing to be covered with matched poplar sheathing ½ in. thick and 3 ins. wide, closely laid and securely nailed to roof framing. Outside of roof sheathing to be painted with brown oxide of iron paint, and then covered with No. 8 cotton duck, and outside of duck covering to be painted three coats of lead and oil paint before trolley board is placed in position. Inner side of roof sheathing to be painted with brown oxide of iron paint. The entire upper deck of roof to be covered with roof mats made of ash slats, placed on ash cleats laid in white lead, and securely screwed to roof framing.

Trolley Board.—To be of best quality white pine, made of two boards 1¾ ins. thick, 6 in. wide and 11 ft. long, placed 4 ins. apart on centre of roof, placed on ash cleats laid in white lead and securely screwed to roof. All parts of trolley board and roof mats to be well painted with lead and oil paint. Bolts to be provided for securing trolley pole base stand, and to be located to suit the...... base. Roof mats to be placed on lower decks at diagonally opposite corners of car, also black steps on corner posts and grab handles on roof at same corners, of black.

Platforms and Vestibules.—Platform outside knees of oak, 3½ ins. thick, 8 ins. wide. Platform inside knees of oak, 3¾ ins. thick, 8 ins. wide. All platform knees to be re-enforced with 5 ins. x ⅝ in. iron plates extending full length of knees and securely bolted to same. Platform floor to be best quality quarter-sawed yellow pine ⅞ in. thick with 2½ in. face, laid crosswise and securely nailed to platform framing. Distance from top of car floor to top of platform floor 6⅞ ins. Platforms to be 4 ft. 10 ins. long from end of car body to outside of vestibule front at centre of car, enclosed at front by stationary vestibule, with folding doors at both sides hung to vestibule corner posts, also folding gates for summer use. Vestibule to have three sash at front, the sash in centre opening to drop, and all other sash to be stationary. All framing parts of vestibule to be of best quality tough ash. Lower part of vestibule fronts to be sheathed with matched poplar sheathing, placed vertically same as on sides of cars, sheathing to be ⅝ in. thick and 2 ins. wide on face and securely nailed to vestibule framing. Inner side of sheathing to be backed with linen scrim and painted same as on sides of car.

Inner side of vestibules to be finished in oak throughout, finish at bottom to be panel work, all finished in the natural color of the wood and varnish.

Hoods.—To be of the street car pattern. The bow to be of oak 1⅛ ins. x 1⅝ ins. steamed and bent to shape. The carlines to be of ash ⅞ ins. x 1¼ ins. steamed and bent to shape, shouldered, glued and securely screwed to bow. Hood carlines against end of car to be of ash, 1¼ ins. x 1½ ins. Hoods to be covered with matched poplar sheathing ⅜ in. thick and 2½ ins. wide, bent to shape and securely nailed to bow and carlines. Outside of sheathing to be painted and covered with cotton duck, and outside of duck covering to be painted three coats of lead and oil paints. Inner side of hoods to be painted same color as outside of car body. Outer edge of hoods to be provided with an iron guard to prevent trolley pole from wearing out canvas covering.

Smoking Compartment.—Each car to have a smoking compartment at one end, 7 ft. 8¼ ins. long between end linings, with longitudinal side seats made of oak and varnished. Partition between smoking compartment and balance of car to have a single sliding door, 25-in. opening. Windows at each side of door opening in partition to be glazed with clear glass; also glass in door to be clear.

Windows.—Eleven on each side of car, and two at each end. Each window opening to have two sash, the upper one to be stationary and the lower one to drop flush with arm rail. All window openings at sides of car to be provided with a hinged casing covering space between sash and inside lining, which will close the opening both when sash are up and down. The lower outside end sash to be made to drop, and the inside end sash to be hinged and fitted with brass wire cloth.

Interior Finish.—Interior finish of car body and vestibules to be of quartered oak throughout, of modern design and secured in place with solid black oval-head screws. End and side linings of oak, ¾ in. thick, with raised panels $\frac{9}{16}$ in. thick.

Doors: Center rails of oak, 6½ ins. x 1$\frac{5}{16}$ ins. Lower rails of oak, 8¼ ins. x 1$\frac{5}{16}$ ins. Upper rails of oak, 4½ ins. x 1$\frac{5}{16}$ ins. Side door stiles of oak, 4½ ins. x 1$\frac{5}{16}$ ins. Center door stiles of oak, 4 ins. x 1 $\frac{5}{16}$ in. Panel mutins of oak 2 ins. x 1$\frac{5}{16}$ ins. Raised panels of oak, $\frac{7}{16}$ ins. thick both sides.

Sash: Bottom rail of oak, 3½ x ¾ in. Top rail of oak, 3⅞ ins. x ¾ ins. Side stile of oak, 2$\frac{1}{16}$ ins. x ¾ in.

Deck sash; Lower rail of oak, 1½ ins. x ¾ in. Upper rail of oak, 1$\frac{3}{16}$ ins. x ¾ in. Side stiles of oak, 1$\frac{5}{16}$ ins. x ¾ in.

Transom sash in ends: Lower rail of oak, cut to pattern, 1¼ ins. a ¾ in. Upper rail of oak, 1 in. x ¾ in. Side stiles of oak, 1⅛ in. x ¾ in.

Ceiling.—Of three-ply birch veneer, plainly decorated and varnished, ceiling and ceiling moldings to be secured in place with screws, and ceiling moldings to be grooved on back to receive the lamp wires. Back of ceiling to be painted with brown oxide of iron paint.

DOORS.—Automatic double doors at each end of car, made of oak with oak panels, hung at top with contra-twist door fixtures. Door in partition to be hung with hangers and track. Door openings at ends of car to be 40 ins. wide and 6 ft. 3 ins. high, and door openings in partition to be 25 ins. wide and 6 ft. 3 ins. high. All doors to have stationary glass.

SASH.—All sash to be ¾ in. thick and made of oak.

DECK SASH.—Eleven on each side of car pivoted and made of oak. The ends of ventilator or monitor deck to be divided into three spaces, with pivoted sash in center opening and stationary glass in side openings.

GLASS—The glass in all windows and doors to be first quality double thick American window glass, imbedded in molded rubber on all edges to prevent rattling. Glass in deck sash to be double thick white chipped, with 1 in. clear edge and imitation bevel.

CURTAINS.—All side and end windows, also outside of end door openings to be provided with curtains. Curtains to be made of .... material, pattern ...... color ...., mounted on .... 1-in. spring rollers and fitted with the .... fixture at the bottom. Curtains on outside of end doors to be made up in same manner as the other curtains, to be placed in a neat oak box over door opening with side pieces extending down to arm rail to form guides for curtain fixtures.

SEATS.—There are to be eight (8) on each side of car in large compartment, six of which are to be of .... Walkover pattern, and four stationary seats; the two stationary seats at end next to vestibule to be placed longitudinal with car, and the two stationary seats next to partition to be placed crosswise. Cushions of all reversible and the two longitudinal stationary seats to be 33 ins. long and the two stationary seats next to partition to be 31 ins. long. Backs of all cross seats to be 22 ins. high, and those of the longitudinal seats to be of same height as side lining (13 ins.). All reversible cross seats to have grab handles on corner of back at aisle end, also movable foot rest and thumb latch on seat back levers. All seat cushions to be 18 ins. wide. All seat and back cushions to be covered with canvas-lined rattan with hard enamel finish. Space between center of stationary cross seat and the first reversible seat to be 37 ins. Reversible seats to be spaced 17 ins. between edges of seat cushions when passengers are facing each other, and 16½ ins. between edges of seat cushions when backs are all turned same way. Aisle through center of car to be 20 ins. wide.

HAND RAILS.—To be placed in smoking compartment only, supported by black ornamental brackets. Rails to be made of oak 1⅛ ins. diameter, with polished black ends. Each rail to be supplied with six (6) padded hand straps made of fancy leather and fitted with black buckle.

FLOOR MATS.—Everett pattern, made of ash slats ⅝ in. thick, ¾ in. wide, placed ¾ in. apart, extending longitudinally in aisle full length of car and sunk flush with the floor.

TRIMMINGS.—Of very best quality black metal, dead finish and secured in place with solid black screws.

GRAB HANDLES.—Long vertical grab handles to be placed on posts at each side of each vestibule entrance, made of 1-in. steel-lined black tubing fitted into black end sockets, 36 ins. long, and securely screwed to posts with solid black oval-head screws.

Window Guards.—Three bar window guards to be placed on outside of all end windows, made of ½ in. heavy black tubing filled with hard wood and secured in place with solid black screws.

Signal Bells.—Two 6-in. steel conductor's signal bells to be supplied with each car, with necessary cords of $\frac{5}{16}$-in. round oak tan leather extending through center of car suspended from ceiling with suitable black hangers with 13-in. drop.

Register.—One .... fare register of latest pattern to be furnished with each car, with necessary cords of $\frac{5}{16}$-in. round oak-tan leather extending along ventilator rail at each side full length of car and onto both platforms, suspended by suitable brackets or guides.

Wiring.—Car bodies to be wired for light and trolley circuits. Light circuits to be arranged for four single lights on each ventilator rail in large compartment and two single lights in upper deck of smoking compartment. All wiring material, sockets and switches to be furnished by the railway company.

Headlight.—Each car to be equipped with one .... headlight complete, arranged to hang on front of vestibule.

Heaters.—Each car to be equipped with sixteen electric heaters, type to be selected by the railway company.

Sand Boxes.—Each car to be equipped with two (2) sand boxes—one at each end at diagonally opposite corners of car, placed under seats, arranged to operate by foot lever, and supplied with removable hose.

Gongs.—Two 14-in steel foot alarm gongs to be supplied with each car one under each platform.

Brake Staffs.—One on each platform, 1¾ ins. round at the bottom, forged tapering to 1 in. round at the top, well braced, fitted with 12½-in. black ratchet brake handle and ⅜-in. twist-link Norway-iron brake chain.

Platform Steps.—Double steps at each platform entrance, sides of steps to be made of steel plate ¼ in. thick, with treads of ash ⅞ in. thick and 8½ ins. wide. Distance between end of car body and inside of platform crownpiece 38 ins. Distance from outside of car side to outside of platform knee 13 ins. Distance from top of platform to first step 11 ins., and from top of upper step to top of lower step 10½ ins. Distance from top of platform floor to underside of bottom step 24 ins. Distance from top of platform floor to top of car floor 6⅞ ins. Edge of bottom step to project 1½ ins. beyond side of car. Outer edge of step treads to be covered with iron molding.

Draw Bars.—Extra heavy radiating spring draw-bar at each end of car, with necessary slides, all securely bolted to car body. Height from track to center of draw-bars when car body is mounted on trucks to be 22½ ins.

Bumpers.—Angle iron bumpers to be placed on front of vestibules, made of 6 ins. x 3½ ins. x ⅜ in. angle iron bent to same shape as vestibule front, and extending full width of same, projecting 6 ins. beyond front of vestibule and securely bolted to platform knees, which project out for that purpose. Height from track to center of bumpers to be 33½ ins.

Material and Workmanship.—All material entering into the construction and finish of these car bodies to be of the very best quality; all sills to be full length without splicing; mortises and tenons to fit each other tightly without false filling, and to be thoroughly white leaded when being put together; all lumber to be of the very best quality and thoroughly well seasoned and dried; and all work to be done on a strictly first class workmanlike manner.

Corner Posts and Headpiece.—To be securely tied together with an angle iron brace let into top of headpiece, corner post and side top plates. Outside of corner post, where it joins plate and headpiece, to be protected by a heavy iron plate. Corner iron to be placed in corners of hoods where the bow joins the rear carline.

Painting.—These car bodies to be painted in the best possible manner, lettered, ornamented and striped as desired by the railway company, and varnished throughout with .... railway varnish. Outside of car to be painted in the following manner: Two coats of pure white lead and linseed oil. After second coat car to be puttied and plastered where necessary. Car to be rubbed with pumice stone and water until a perfectly smooth surface is obtained. Two coats of flat body color, and if necessary an additional coat will be put on, depending on color used. One coat color and varnish, on which striping and lettering will be done. Two coats............rubbing varnish, second coat to be rubbed with pulverized pumice stone and water. Two coats............railway body varnish. All striping to be done in gold. Lettering and numbering to be of same size and style as shown by photograph to be sent by railway company. Roof of cars to be painted three coats of lead and oil paint, each coat to be allowed to dry before the succeeding coat is applied. Inside work to be finished in the following manner: All parts of inside woodwork of car and vestibule to receive one coat of oil filler, one coat of pure linseed oil, and three coats of............rubbing varnish, last coat of varnish to be rubbed to a cabinet finish. No shellac to be used on any part of the cars.

Inspection.—The railway company shall have the privilege of sending a representative to the shops of the car builders to inspect and examine the cars while being built.

Trucks, Mounting Motors and Installing Electrical Equipment.—The company to furnish and deliver free of any expense at the works of the car builders all necessary trucks, motors, wire, switches, sockets and all other electrical equipment for these cars, and the car builders to install same without any extra charge.

Time of Delivery.—These car bodies to be delivered complete, f. o. b. cars, ...on or before............19...., subject to delays caused by fire, labor trouble or any other cause beyond the control of the car builders.

NOMENCLATURE OF CAR PARTS.

(See Figs. 288, 289, 290.)

Abreviations.

WOODWORK.		METAL WORK.	
O	Oak	C. I	Cast Iron
A	Ash	W. I	Wrought Iron
Y. P	Yellow Pine	M. I	Malleable Iron
P	Poplar	W. S	Wrought Steel

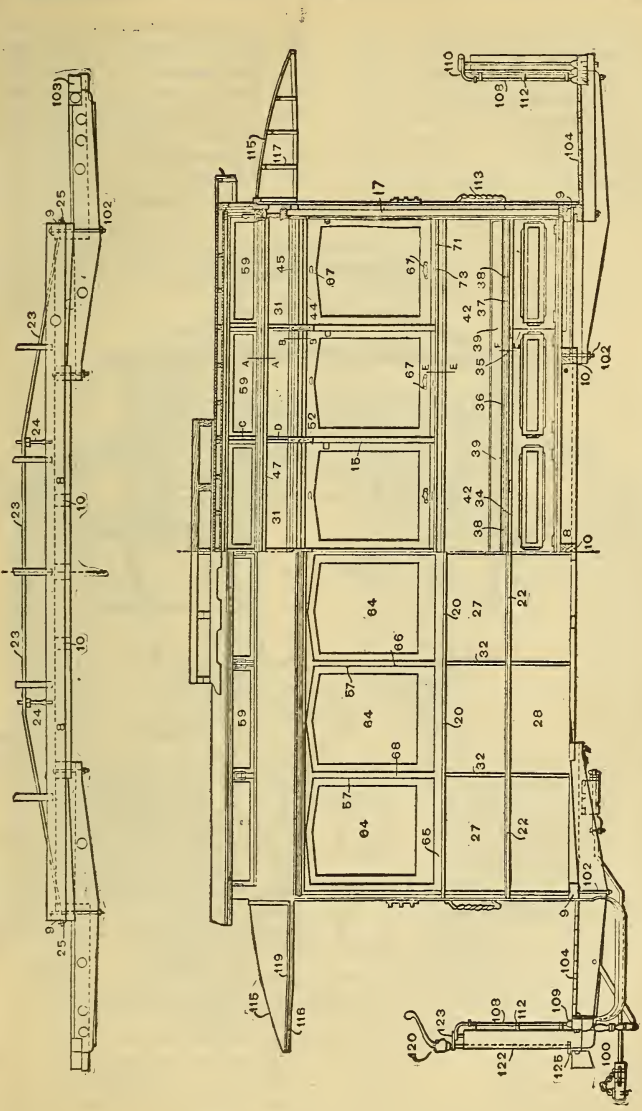


FIG. 288.—NOMENCLATURE OF CAR BODY PARTS.

8. Sill, Y. P., O.
9. End Sill, O.
10. Transverse floor beams, O.
11. Cross tie rod, W. I.
15. Side post, A.
17. Corner post, A.
18. Door post, A.
19. Belt rail, A., Y. P.
20. Belt rail band, W. I., half oval.
56. Upper deck.
57. Deck bottom rail.
58. Deck post.
59. Deck window.
61. Deck end ventilator.
64. Window.
66. Window stile.
67. Sash lift.
68. Sash stop bead.

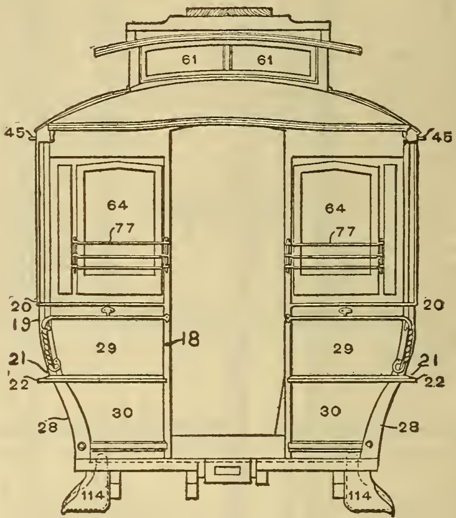


FIG. 289.—END VIEW OF CAR BODY.

21. Fender rail, A., Y. P.
22. Fender guard, W. I., half oval.
23. Body truss rod, W. S.
24. Body queen post, W.S., M. I., C. I.
25. Truss rod plate, W. I., C. I.
27. Outside panel, Convex P.
28. Lower outside panel, Concave P.
29. Upper end panel.
30. Lower end panel.
31. Inside frieze panel.
32. Panel strip.
33. Panel furring.
34. Seat bottom.
35. Seat leg.
36. Front seat rail.
69. Window blind.
72. Window blind mullion.
73. Window blind lift.
77. Window guards.
78. Door stile.
79. Door mullion.
81. Middle door rail.
82. Top door rail.
85. Mirror.
86. Door case sash.
89. Fare wicket.
91. Sliding door handle.
102. Platform timber clamp.
103. Platform end timber or crown piece.

38. Back seat bottom rail.
39. Back seat rail.
40. Lower seat back rail.
42. Seat back board.
43. End seat panel.
44. Upper belt rail.
45. Window ledge.
47. Plate.
48. Eaves moulding.
49. Window blind rest.
50. Window sash rest.
51. Outside window stop.
52. Inside window stop.
53. Carline.
108. Platform post.
109. Platform post boss washer.
110. Platform rail.
112. Dash guard straps.
113. Body hand rail.
114. Side step.
115. Hood.
116. Hood bow.
117. Hood carline.
119. Hood moulding.
120. Brake shaft crank.
122. Brake shaft.
123. Upper brake shaft bearing.
125. Brake ratchet wheel.

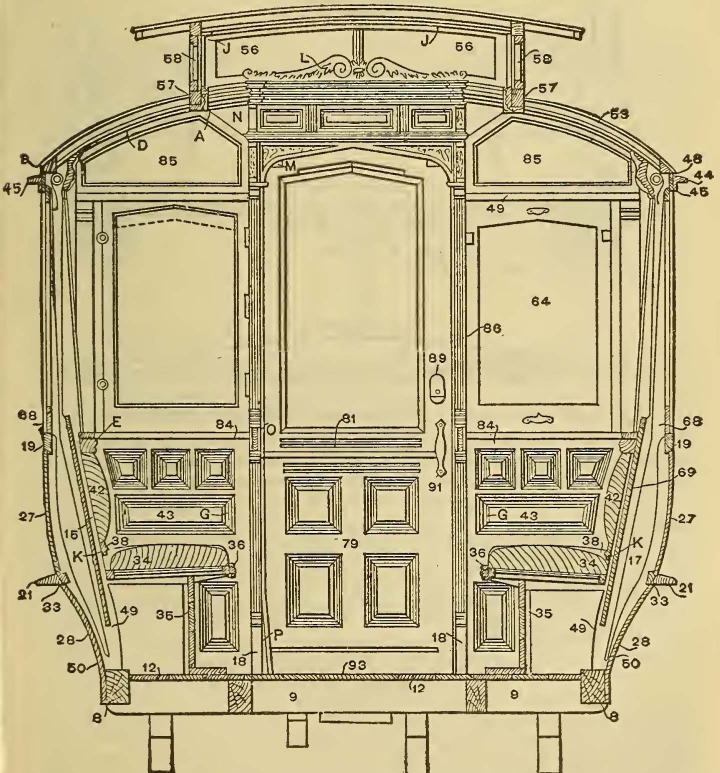


FIG. 290.—SECTIONAL VIEW OF CAR BODY.

The modern tendency is to lengthen car bodies, especially where there are many short distance riders, since it leads to increased comfort and the probability of the passengers always obtaining seats, and this will attract more traffic although the cost for operating is very slightly increased. Where double trucks are substituted for single trucks, the car body can be lengthened 4 ft. and increased in weight proportionately without perceptibly affecting the demand on the power station, or increasing the power supply per equipment; and, the labor item being a constant, the cost per passenger will be less.

SPLICING CAR BODIES.

A number of roads have increased the length of their car body by cutting in two and splicing. The Union Traction Co., Philadelphia, has followed the following practice: Taking its short 18 ft. car bodies, which had six windows,

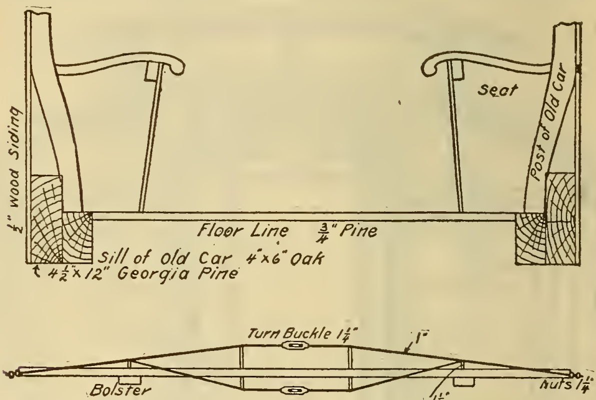


FIG. 291.—METHOD OF SPLICING CAR BODIES WITH WOODEN BEAM.

the body is sawed in two. The side sills are cut dovetail, and the inserted lengthening sill is dovetailed into the side sill. The car is lengthened so as to just receive two more window frames, which gives a car body length of 24 ft. when complete. The inserted sills are only used to hold the uprights. For strength a steel angle is fitted to each side of the car for the length of the body. The sides of the angle are steel plate, L-shaped, 6 ins. x 4 ins. and ⅝ in. thick, the 4 in. side being placed under the sill. In addition to this angle iron, a truss rod is placed behind the sills to reinforce the angle, and two maximum traction trucks are placed under the body.

Another method is to splice two small cars together. This has been carried out by one company in the following way: The two bodies are set on horses; the back end is removed from one of these bodies and the front end of the other. The corner posts and end sills are ripped in half. Then the two bodies are butted together and fastened with ⅝-in. carriage bolts, placed so as to be out of sight. The sills are reinforced by ½-in. angle iron plates, extending 4 ft. each way from the splice. The old panels and water rails are removed, and a piece of Southern pine, 4½ ins. x 12 ins. x 32 ft. is set into it flush with the bottom of the sill, and bolted through the old sill every 22 ins., using ⅝-in. bolts with cast washers on the pine side. On each side of the splice two rods ¾-in round went clear through the body. The 4½ in. x 12 in. sill was framed to fit the top curvature of the post. Fig. 291 shows a section of this car body and the method of trussing to support it.

To give sufficient strength to the roof, two pieces of Southern pine, 2 ins. x 8 ins., extend the length of the roof and fit into an angle of ½-in. iron at each end. Two tie rods, ¾ ins. x 32 ft. x 5 ins. pass through these angles with double nuts on each end. By using these tie rods it is possible to give the roof any desired cambre to hold it there. The 2 in. x 8 in. pine pieces are 14 ins. from the roof at center of the car. On top of this truss is mounted the trolley stand, and a double truck is placed underneath the car.

TRUCKS.

Test on Peckham Truck.—All castings except center bearing and side poles were malleable iron; side pieces were formed of 4 bars of flat iron, riveted to pedestals, placed in pairs, to take compression and tensile stresses. The truck was the same as a 14-A, except heavy enough to carry loads of 30,000 lbs., with a factor of safety of 6. The test was made by the Robert A. Hunt Co. on a wheel press.

Load, Tons.	Total Deflection, Ins.	Permanent Set, Ins.
5	.00	.00
10	.00	.00
15	.02	.00
20	.03	.00
25	.04	.00
30	.07	.03
35	.16	.10
40	.19	.13
45	.26	.17

At 50½ tons, the lower tension members broke through the first rivet hole, and the malleable casting at one end.

Figs. 292–294 shows the No. 14 Peckham truck. The length of the car body, upon which the trucks were mounted, was 24 ft. The length over all 33 ft. The distance from rail to bottom of car sill, 28 ins. The distance from rail to car steps 16 ins. The width of car body, 7 ft. 7 ins. The diameter of axle, 4 ins. The wheel base on trucks, 5 ft. 7 ins. Diameter of wheels, 30 ins.

Method of Increasing Traction.—It has been urged against the double truck that the weight on the driving wheels was not sufficient to mount grades. This has been successfully overcome in one instance, where a 14½ per cent grade had to be mounted, by placing double trucks under the car, but both motors under the rear truck. It must also be borne in mind that the hanging of the motor forward of the front axle of the car increases the weight on the driving wheels, on account of the additional weight of the motor; in this way greater tractive effect can be given for maximum traction or double truck cars.

In descending grades there is twice the coefficient of adhesion between the eight wheels that there is with the single truck four wheels. As a result of careful tests between the double and single truck, it is found that the double truck requires less power, for the same car body, than the single truck, especially where the single truck allows considerable teetering of the car. In one case a car body, weighing 3 tons more with a double truck and the same motors, showed 1.21 kw

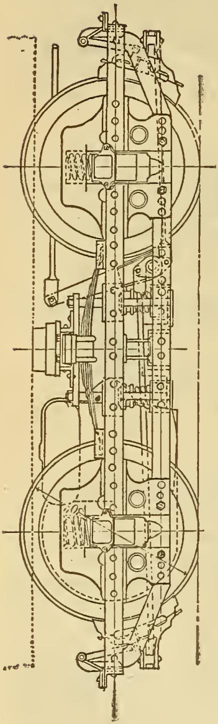


FIG. 292.—PECKHAM NO. 14 TRUCK, SIDE VIEW.

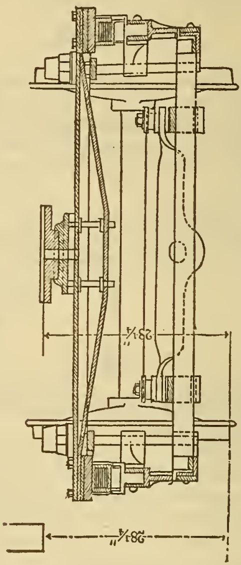


FIG. 293.—SECTION THROUGH BOLSTER.

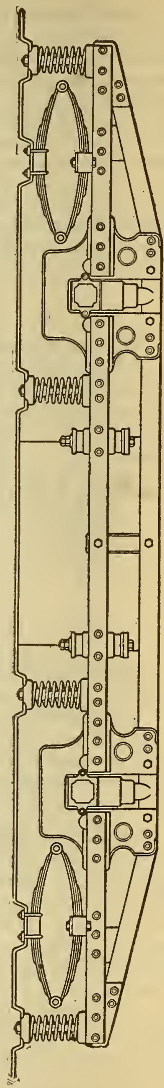


FIG. 294.—PECKHAM CANTILEVER TRUCK, SIDE VIEW.

per car mile, whereas a single truck, with the same motors, showed 1.37 kw per car mile over the same track. The only change was made in the truck.

In looking for the difference in efficiency of these two types of trucks, a cyclometer was put up on each driven axle, and it was found that the actual slippage ranged between 10 per cent and 18 per cent between the front and rear wheels when the car was on a level and when climbing a 5½ per cent grade, the front wheel having the slippage. It must be remembered that, in case of wheels slipping, the heating of the track and wheel is lost energy, and produces no useful result.

SELECTION OF TRUCKS.

It is probable that, even with the cantilever extension truck, a 22-ft. closed car body (being about 30 ft. over all), is approximating the limit of a size of body which can be successfully carried on a 7 ft. wheel base. Fig. 294 shows the cantilever extension truck, which is the size used under a 22-ft. car body successfully.

The spring support to the body is generally differential, that is, an elliptical double or single takes the weight of the car body light. The best method sets the car body over an elastic support, which will not be too light at low loads, allowing the car body to oscillate or pitch, and not coming down too hard under heavy loads. The springs should be so arranged among themselves as not to repeat the movement over bad joints, but their interaction should tend to damp out any oscillating effect.

As the load comes on the car body, the elliptical springs are depressed. When they are compressed to a point where they lose their resilience the weight is taken up by spiral springs. The arrangement of springs under the truck to support the weight varies with different truck manufacturers. The points, however, which should be obtained in truck construction are: rigidity of frame to withstand the stress tending to throw the axles out of alignment on rounding curves; the power to resist the longitudinal strains thrown on the truck frame by sudden changes in track contour, and reduction of uncushioned weight on the wheels. The truck must be so constructed as to allow easy access to motors, wheels and journal boxes. The attachment to the car body should be made so as to be readily removable. The method of constructing the truck frame can be either riveted bridge construction or solid side frame.

CAR AXLES.

Cold rolled steel and wrought iron are both used for axles, wrought iron having the preference. The diameter varies from 3¾ ins. to 4 ins.; 3¼ ins. is the most common diameter for the journals. The gear keyway is generally made for a key ¾ in. wide and cut ½ in. deep in the axle. Axles are found to break where square corners are present for the fracture to start. All corners should, therefore, be turned with fillets. If the keyway is cut with a milling machine so that it has sloping sides, the axle will be less liable to break at this point than if the keyway is drilled at each end and slotted out.

The size that the axle should be turned before forcing on the wheels can only be determined by experience and depends upon the density of the wheel hub and the axle. The length of the axle for standard gage varies with the different trucks. The Taylor takes an axle 6 ft. 3 ins. long; Peckham, 6 ft. 4⅜ ins. and also 6 ft. 6⅜ ins.; Brill, 6 ft. 5 ins.; McGuire, 6 ft. 5 ins. and 6 ft. 6 ins.; Bemis and Baltimore, 6 ft. 5¼ ins.; Diamond, 6 ft. 5½ ins.

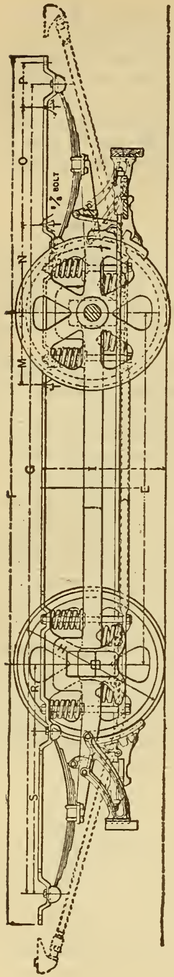


FIG. 295.—BRILL TRUCK, SIDE VIEW.

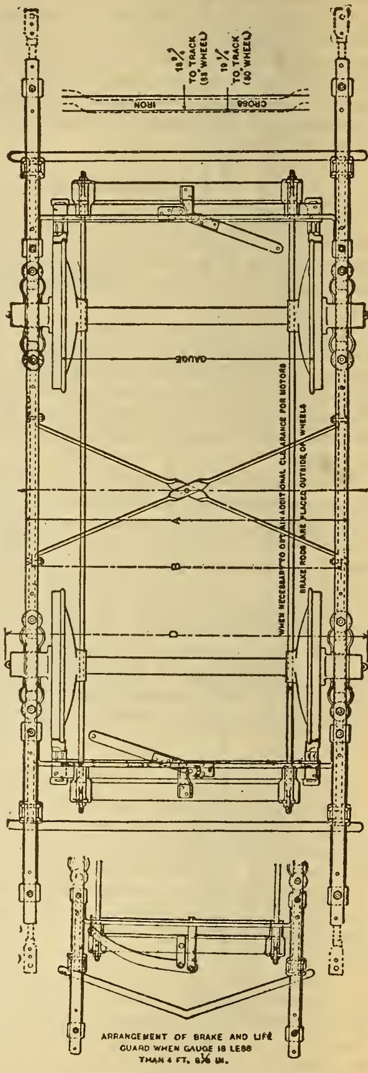


FIG. 296.—BRILL TRUCK, TOP VIEW AND BRAKE RIGGING.

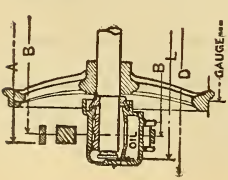


FIG. 297.—BRILL TRUCK, WHEEL AND BOX.

APPROXIMATE WEIGHT OF MOTOR TRUCKS.

GAGE, 4 FT. 8½ IN.

MAKE OF TRUCK.	Weight of Wheel. Lbs.	Diameter of Wheel. Ins.	Weight of Truck. (Bare) Lbs.	Weight of truck equipped with G. E. 800 motors. 1 Motor. Lbs.	2 Motors. Lbs.
Bemis, four-wheel..........	250	30	3,123	5,000	6 800
Brill, four-wheel.............	300	30	3,500	5,300	7,100
McGuire, four-wheel.........	300	30	3,000	4,800	6,600
Tripp, four-wheel............	280	30	3,600	5,400	6,900
Bemis, eight-wheel	300	30	6,240	4,900	.....
Brill, (maximum traction)...	300 / 200	30 / 22	5,400	4,500	.....
Tripp, eight-wheel	280	30	6,400	5,000	.....
Robinson, radial.............	300 / 200	30 / 24	5,000	6,800	8,600
Peckham, four-wheel........	300	30	4,000	6,200	8,000
" eight-wheel.......	300	30	.....	.....	.....

STANDARD DIMENSIONS FOR BRILL NO. 21-E. TRUCKS.

(See Figs. 295, 296, 297.)

GAGE.	Width over top plates. A	Centres of top plates. B	Width over journal boxes. D	Length of axle. L	Wheel base. E	Total length. F	Spring base. G
Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
4 0	5 10⅞	5 8⅛	6 10⅞	6 3¾	6 0	14 3	13 2
4 8½	6 0	5 9¼	7 0	6 5	6 6	14 9	13 8
5 0	6 2⅜	5 11⅝	7 2⅜	6 7¼	7 0	15 3	14 2
5 2½	6 5⅜	6 2⅝	7 5⅜	6 10¼	7 6	15 9	14 8
5 3	6 5⅜	6 2⅝	7 5⅜	6 10¼	8 0	16 3	15 2
					8 6	16 9	15 8
					9 0	17 3	16 2

Diameter of wheel. H	Height of truck, with weight of body. I	M	N	O	P	R	S	T
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
30	25⅛	16	19⅝	18⅜	10	15	28	¾
33	26⅝							

CAR WHEELS.

The following table gives the composition of car wheels which showed a long life and stood thermal and blow tests.

	ANALYSIS OF CAR WHEELS					
	Which Stood Thermal Test for 60 Mins.		Which Stood 40 or More Blows Drop Test.		Which Gave 5 or More Years of Service.	
	Max.	Min.	Max.	Min.	Max.	Min.
Graphite	3.28	2.65	3.31	2.65	3.18	2.23
Combined carbon	.95	.32	.90	.55	1.24	.56
Silicon	.75	.50	.70	.50	.94	.58
Manganese	.53	.20	.46	.24	.34	.13
Sulphur	.088	.055	.086	.040	.085	.047
Phosphorus	.48	.35	.52	.36	.49	.25

It will be seen that these limits are rather wide, but below are given what are considered to be the desirable limits for the chemical constituents of wheels:

Desirable Wheel Analysis.

Graphite	2.75	per cent	to	3.00	per cent.
Combined carbon	.50	"	"	.75	"
Silicon	.50	"	"	.70	"
Manganese	.30	"	"	.50	"
Sulphur	.05	"	"	.07	"
Phosphorus	.35	"	"	.45	"

The proper amount of manganese is an important element, for upon it depends the capability of the wheel to stand the preliminary test and take a good deep chill.

There are a great variety of methods and variation of mixtures used by the different wheel manufacturers, on which they base their mileage guarantees, but the following are the elements of general specifications for car wheels:

They must all be cast in true metallic chills of the same internal diameter and uniform cross-section. The body of the wheel to be of clean, soft, grey iron smooth and free from blow holes, The hubs to be solid and free from drawing. The tread and throat of the wheel must be smooth and free from deep and irregular wrinkles, slag or sand wash, and practically free from chill cracks and sweat. The depth of clean white iron should not exceed ⅞ in. at throat and 1 in. at middle of tread, nor be less than ⅜ in. at the throat or ½ in. at middle of tread; nor should there be more than ¼ in. in variation of the depth of chill throughout the same wheel. The blending of the grey with the white iron must be without distinct line of demarcation. See Fig. 298-300.

In each wheel, when a true metallic ring is placed so as to bear on the cone no part of its circumference will stand more than $\frac{1}{16}$ in. from the tread of the wheel. No wheel made in a solid chill will be passed whose circumference differs from 1⅝ in. or less than ⅞ in. from the circumference of the chill in which it is made. Wheels cast in contracting chills should not differ more than 2 ins. from the circumference of the chill. All wheels during inspection must stand three heavy blows of a 6-lb. sledge under the flange and between the brackets, and must withstand a pressure of 50 tons when being forced on the axle.

With each pouring of 100 wheels two additional ones must be furnished for the following tests. One wheel is placed, flange downward, on an anvil block weighing not less than 1700 lbs., set on 2 ft. of rubble masonry and having three supports for the wheel to rest on, not less than 5 ins. wide. The wheel is then struck centrally upon the hub with a weight of 140 lbs. falling from a height of 12 ft. The wheel should stand 15 blows without breaking. If it breaks in only two places and the depth of chill is uniform, the wheels may be accepted providing they stand boring and mounting with 50 tons pressure.

The thermal test is carried out as follows: The test wheel is laid, flange down, in the sand, and a channel way 1½ ins. wide and 4 ins. deep, must be molded with green sand around the wheel, the clean tread forming one side of the channel way. This is then filled with molton cast iron, which must be hot enough when poured to form a ring when the metal is cold that shall be solid and free from wrinkles or layers. The time of pouring is to be noted, and two minutes after pouring the wheel is to be examined.

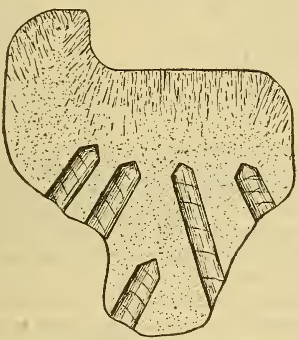


FIG. 298.—CHILL FOR CAR WHEEL AND METHOD OF TESTING.

The weight of car wheels has gradually increased from 250-260 lbs. to 325-350 lbs. for 30-in. wheel, and to 370-380 lbs. for 33-in. wheel. For interurban high-speed service the 38-in., 400-lb. wheel is now coming into favor.

Sections of car wheels are shown in Figs. 299-300.

The mounting of the wheels on the axle is done as follows: The axles are pressed in ¼ in. less than the gage line between the center of the fillet between the flange and the tread, where the road is not in good alignment and where 60-lb. rails are used. This is to allow of lateral play and avoid cramping the flanges and wearing them unduly. The surface of the flange presented to the special work at frogs and switches is becoming more of a flat surface than formerly to avoid wearing and cutting these parts of the track. With a grooved rail the flange end should present as much of a cutting surface as possible, in order to clear the groove of dirt and not pack in at the bottom of the groove and increase the power necessary for operating the car. The outside flange should have a slight slope to prevent cutting into guard rails, and the tread should not overhang the head of the rail so as to come in contact with paving blocks or similar obstructions.

Flat Wheels.—Flat wheels are primarily caused by sliding and grinding a flat on the wheel. There are a number of causes assigned for this trouble. One is that the wheels which become flat were not perfectly true with respect to the axle so that as the brake shoe was drawn up to the wheel it locked the whee

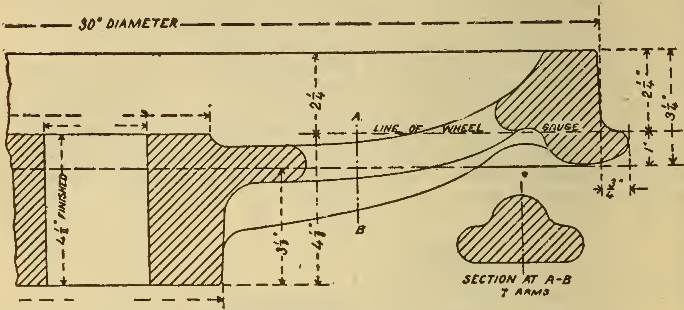


FIG. 299.—SECTION OF NEW YORK CAR WHEEL, 30 INCHES.

when the largest diameter rolled against the shoe and tended to stop the wheel always at one point, thus focusing the wear at one place and producing flats. In new and old wheels, where the chill first wears through, a soft metal will be presented to the attrition between the wheel and rail in braking the car. The retardation is caused by the difference between the length over which the car passes, and the distance through which the wheel rolls. The maximum retardation is

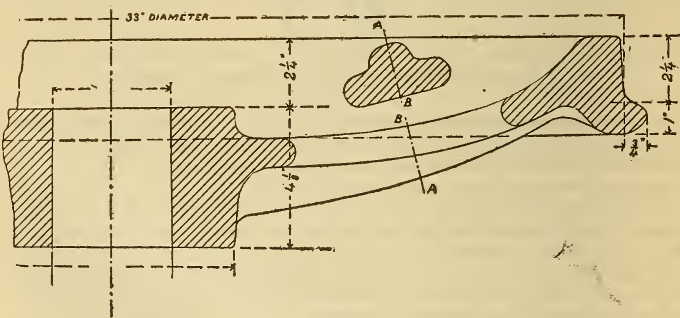


FIG. 300.—SECTION OF NEW YORK CAR WHEEL, 33 INCHES

approximately when this difference is 22 per cent, and falls when the difference passes this point until the car slides.

The thermal test on car wheels is an important one, for the foot tons in the moving equipment appear as energy dissipated in the rim of the wheel, at the brake and under the brake shoe.

BRAKES.

The leverage in hand brakes varies between 40:1 and 72:1, depending upon the weight on wheels, grades and conditions of track. The amount of power a motorman can exert on a brake wheel is given in the following table.

POWER OBTAINED BY DIFFERENT MOTORMEN ON BRAKE WHEEL.

Weight of motorman. Lbs.	Gradual pull with one hand. Lbs.	Jerk with both hands on hand wheel. Lbs.	Emergency jerk with both hands on hand wheel. Lbs.
140	112	135	275
200	135	275	385
287	145	235	312
175	125	212	285
153	125	245	310
185	150	200	300
170	150	275	350
155	135	210	325
135	110	175	325
135	125	250	350
160	125	250	405
176	100	200	400
185	276	250	375
	Av. 131.7	Av. 224	Av. 338.23

The pressure on the brake shoe should not exceed the pressure between the wheel and rail. The effect of speed, brake pressure and traction coefficient is given in the following table for hand brakes.

TABLE SHOWING RELATIONS OF SPEED, BRAKE PRESSURE AND TRACTION COEFFICIENT.

Speed revolutions per minute 33-in. wheel.	Brake pressure. Lbs.	Traction Coefficient. Lbs.	Traction Coefficient. Per Cent.
Varying, 150	900	87.4	9.7
125	900	91.7	10.2
100	900	99.8	11.1
78	900	118.	13.2
56	900	133.	14.8
38	900	150.4	16.6
20	900	154.	17.1
4	900	174.6	19.4
Constant, 105	300	29.4	9.8
	500	50.5	10.1
	750	91.	12.
100	1,150	125.	11.2
	1,500	178.	12.
	2,200	305.	14.4
94	3,780	488.	13.2

The brake rigging takes a number of forms, the inital effort being given by the motorman through a brake handle on the wheel, which wraps a chain around the brake staff. In some cases the brake staff has a pinion which engages in a

RECORD OF CAR

Materials.

No.	Weight of Cars.	Mileage of Wheels.	Mileage of Shoes.	Stops per mile.	Gradients
1-7	No. Records at all				
8	12 to 22000	Abt. 225000	Abt. 75000	....	As high as 10% & plenty of them
9	....	....	....	....	....
10	....	....	....	....	....
11	....	....	....	....	6% heaviest
12	....	....	....	....	....
13	....	....	....	....	....
14	About 12000	25000 to 30000	....	....	....
15	15000	35000	3000	....	Not over 7%
16	4 to 6½ tons	20000 to 60000	4 to 7000	Abt. 10 per m.	2½ to 5½%
17	12000	55244	4864	5 per m.	3 to 6%
18	Cab. 7500 E. 14500	40000	7000	8 per m.	Level
19	6 to 8000	Abt. 40000	Abt. 12000	....	0 to 12%
20	4 to 5 tons	....	....	....	Highest 2%
21	About 6½ tons	30000 to 32000	....	....	....
22	....	....	....	Very frequent	One of 10%
23	....	....	....	....	8 to 9% in places
24	7 to 8 tons	One year	9000	Very frequent	6%
25	12 to 15000	30000 to 40000	5 to 7000	Not frequent	About level
26	5 tons	Not worn out but flat in 5 years	6000	5 to mile	0 to 9%
27	4 to 6000	One year	2 to 8000	Every 300′	0 to 6½%
28	Cab. 7000 E. 16000	33000 27000	....	As usual in cities	Abt. 2½%
29	11000	45389	....	....	5% heaviest
30	20000	30000	4500	....	....
31	5½ tons	20000 to 24000	10 to 14000	Every 500′	Not over 2%
32	10000	Abt. 36000	1500	20 per m.	4 to 11%
33	Mo. 16000 Trail 6000	....	....	....	3 to 7%
34	8 to 9 tons	4000 to 30000	Comp. 20000 C. 1.8 to 10000	Usual in cities	Max. 3%
35	8 tons	35000	45000	7 to m.	7%

WHEELS AND BRAKE SHOES.

No. of Truck Patterns.	Shoe Patterns. No. Hangers.	Shoe Patterns Separate Hangers.	Stand Shoe Wanted	Stand Shoe Hanger Wanted.	Remarks.
4 Brill	....	1	....	Yes	Shoes wear down to ¼ in. thickness or less before giving out.
....	....	....	....	Present practice	Shoe interior and fit standard hanger.
1	....	....	....	....	Shoes from Bemis Co. only.
1	....	....	....	....	
5 or 6	....	....	....	Yes	Use shoe as made by truck manufacturers.
3	6	....	Not possible	Yes	60% chilled iron, 20% soft Lappin.
3	....	....	Yes	....	Chilled iron in shoes.
2	....	....	....	....	Hard iron shoe to brake on tread only.
2	....	3	Not possible	Yes	60% soft I; C. I. with wood, also with steel plugs.
1	....	1	....	....	Medium C. I.
1	....	1	....	Yes	Congdon shoe (cast steel plugs in C. I.)
2 Brill	....	....	....	Yes	Soft iron and wood, ill-fitting hangers.
2	....	....	....	Yes	Ordinary C. I. shoe.
2	....	....	....	....	Chilled I. shoes, 2 patterns.
2	1	2	....	Yes	Soft I. with wood plugs.
2	....	....	....	Yes	Soft iron shoe.
4	2	1	....	Yes	Have used soft I. & hard I. and iron and wood plugs.
6	3	3	....	Yes	Have used soft I. & hard I. with wrot. plugs & wood.
4	....	....	....	Most emphatically Yes	Same as 25 above.
4	2	2	....		
1 each railway	....	Loop hanger bolted to brake bar	....	Durable but hard to keep good fit	Prefers hard I. Thinks soft I. wears wheels faster than hard I. Impossible for one shoe to suit all Ry. men.
2	....	1	....	Yes	Congdon shoes.
4	....	1	....	Yes	C. I. with wrought I. plugs.
1	....	1	....	Yes	McGuire type shoe, chilled I. wheels.
1	1	....	....	Yes	Hard C. I., 4 steel segments 3 ins. apart.
1	....	All	....	Yes	Soft C. I. and same with wrought I. plugs.
2	1	1	....	Yes	Soft C. I. and comp. shoe.
3	....	2	Yes	Yes	Soft C. I.; hard C. I., C. I. with wood plugs. Wood.

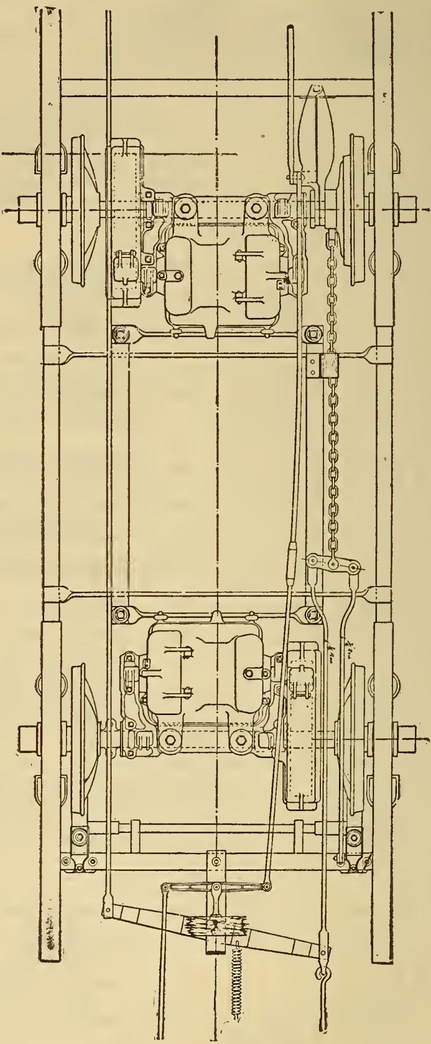


Fig. 301.—Price Friction Brake.

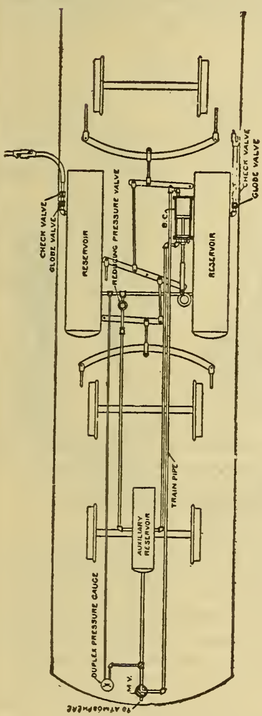


FIG. 302.—MAGANN STORAGE AIR BRAKE.

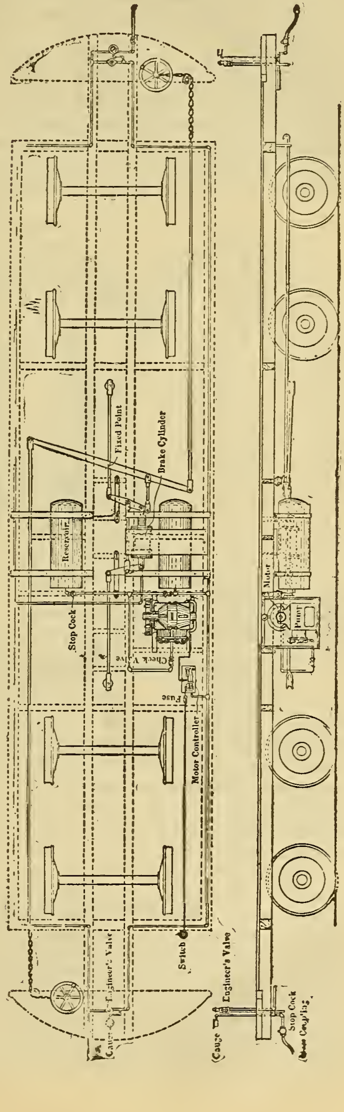


FIG. 303.—CHRISTENSEN AIR BRAKE; ELECTRICALLY DRIVEN.

gear, to which is attached a sprocket through which the chain is wound; this pulls the brake rod attached to the end of a brake lever which is connected to the brake beam by which the shoes are forced against the wheel. There are a number of adjustments for the stretching of the brake rod and the wear of shoes. The brake rigging has to be so aligned that there will be no cramping of the brakes when the equipment passes around curves.

In the Price Momentum Brake, instead of the brake staff directly transmitting the power necessary to draw the brake shoe against the wheel, the brake staff is connected to a clutch. This clutch actuates a drum which winds the brake chain around the car axle and pulls the brake shoe against the wheels. Fig. 301 shows the general construction of this arrangement, the end of the brake chain being

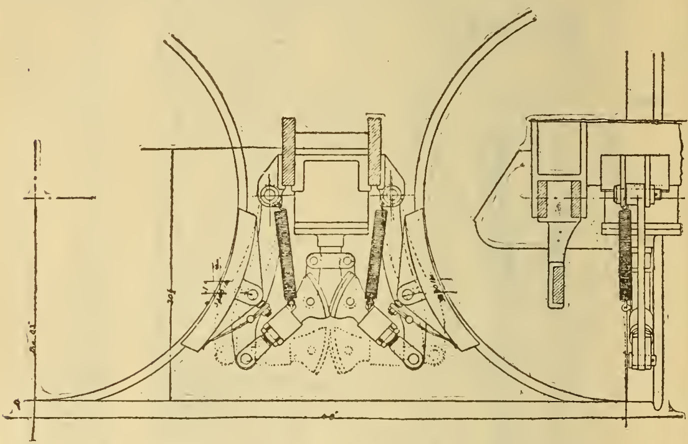


FIG. 304.—STANDARD AIR BRAKE FOR DOUBLE TRUCK CARS.

attached to the drum sleeve on one of the axles. This drum is not keyed to the axle and does not turn with it except when a stop is to be made. By a series of levers the edge of the drum, which is in the form of a disc, is then pressed against a corresponding disc on the inside of the car wheel. Between the two discs is a leather washer to take up the wear. The friction caused by pressing the drum against the car wheel causes the former to revolve, winding up the chain and setting the brake.

Auxiliary power brakes may be actuated by compressed air, or the current generated by the motors. In air brakes the compressed air may be stored or produced by an axle drum or motor driven compressor. The Magann storage system is shown in Fig. 302. The compressed air is produced by one or more steam or electric air compressor plants located at the power stations or car houses, where there are large storage tanks and drip tanks connected therewith to eliminate moisture. The pressure carried is generally 300 lbs. per square inch. From the storage tank the supply pipe is taken to some locality convenient to charge the reservoirs carried on the cars, which have an aggregate capacity of 20 to 35 cu. ft. The air is first reduced to a pressure of 20 to 50 lbs. per square inch, by a reducing valve according to tonnage and operating conditions, before it reaches the auxiliary reservoir, from which the brake cylinder is supplied through the controlling valve under the hands of the motorman. From 400 to 600 stops can be made without recharging.

The axle driven compressor has the compressor pump geared to one of the car axles, and an automatically controlled valve, by which it keeps the reservoirs charged. The electrically driven compressor has an independent motor with an automatic switch, actuated by the initial air pressure so as to throw the motor in and out as the pressure rises and falls between fixed limits. The general arrange-

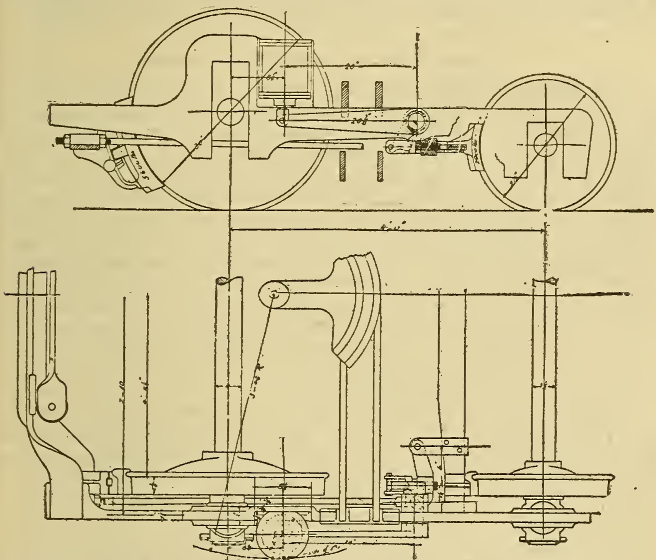


FIG. 305.—METHOD OF APPLYING STANDARD AIR BRAKES TO MAXIMUM TRACTION TRUCKS.

ments on the car of the Christensen electrically-driven compressor and brake are shown in Fig. 303.

Fig. 304 shows the Standard Company's method of applying the air cylinder to double truck cars. Fig. 305 shows methods of applying the air cylinder to maximum traction trucks.

THE MOTOR EQUIPMENT.

As long as the insulation is maintained the current through the motor follows the proper paths and the motor can be operated. Temperature, oil, moisture, as well as time, all tend to depreciate the insulations on these conductors. A practical limit to heating is the ability of the various materials used for insulation to endure the high temperature without perishing or losing their insulating qualities, and in order to obtain a long life from a motor its temperature should not rise 40 degs. Cent. or 70 degs. Fahr. above the air. This brings approximately the ultimate temperature of the motor to 62 deg. Cent. or 143 degs. Fahr. in summer, and to 54 degs. Cent. or 129 degs. Fahr. in the winter, under working conditions. A motor raised above these temperatures will gradually carbonize the insulating material between the coils on the armature and the body of the armature, as well as between the field coils and their cores.

The cotton insulation and covering on the windings will become charred, and the stress to which these windings are submitted on opening the motor circuit by the controller, will tend eventually to pierce them and break down the insulation. With the exception of the mechanical wear on the commutator and the bearings, the whole problem of motor repairs is one of successful insulation.

CARE AND REPAIR OF MOTORS.

The Fields.—The fields of all railway motors are wound with double cotton covered wire. There is a new wire insulated first with asbestos and then cotton over this; the advantage of this double insulation is that if the cotton becomes charred the asbestos will still offer sufficient resistance to prevent adjacent layers of wire from short circuiting out the turns around the field. The field windings for each of the railway motors generally used will be found under data for eaeh motor. The general precautions to be used in winding are common to all of them. Some motors require the field to be wound on forms, and other methods of design have a field spool on which the wire is wound directly. In both cases it is advisable to varnish each layer of wire. Shellac has been advised for this purpose, but it is nearly impossible to dry out a coil thoroughly which is filled with shellac, and the oxidizing of the alcohol tends to carbonize the cellulose in a cotton winding, and in this way it neutralizes the good effect that might result from the lacquer. Never use wood alcohol for this purpose, it is deliquesent, whereas grain alcohol will maintain the insulation resistance.

In some cases it is advisable to wind the field coils dry and dip into an insulating varnish and hang up to drain and dry out. If the field coil is warmed before it is dipped into the varnish, the varnish will soak completely in and fill all interstices with a good insulator which will prevent the entrance of moisture into the coil. After this treatment the coil is insulated and different manufacturers advise different methods, but to cover the coil first with mica or micanite and overlap this medium so that there are no seams left, and then tape this over with two layers of adhesive tape, and over this cover with canvas, and finally paint with some good air-drying asphaltic insulating varnish, is one of the approved methods of insulation. This treatment requires that the field coils be baked before they are used, so as to thoroughly dry out all the solvents used in the insulation.

Where the field coil is wound directly upon a core it should be thoroughly insulated with mica, canvas and duck, and the edges of this insulation should project beyond the field coil so that they can be lapped over after the field coil is completed, and over the overlapped insulation should be wound adhesive tape in the same direction as the winding of the wire. This should then be painted over with asphaltic varnish. The field terminals or lugs which project from the surface of the core should be specially insulated, since this is the point where moisture enters the field coil. The tape should be brought up close to these lugs and the wire leading from them should be well taped before the insulation is put on the field coil. This point should be well treated with varnish and paint. In a few types of motors the field coils are further protected by being encased in sheet copper.

A well insulated field coil should stand the following test:

It should lie in an inch of water for ten hours without its insulation falling below 400,000 ohms. If placed on the pole piece, a difference of 2,000 volts between the field winding and the pole piece, or the field winding and its spool, should not break down this insulation. The field spool should be maintained at 140 degs. Fahr. for 10 hours without the insulation resistance of the coil falling when again cooled. It is well to apply these tests, when using any new material for insulation, on several field coils before it is adopted, as there are many proposed insulating compounds which are seriously impaired in their usefulness when maintained for a length of time at an elevated temperature. This condition of temperature arises in practice when the motor is subjected to an overload or an improperly handled controller.

The Armature.—The break-downs of a street railway armature are caused by heating, flashing at the brushes, and rubbing of the armature body on the field. Oil and water form the principle external troubles, and crosses, grounds, open coils, short circuits and grounding of commutator are the principal internal troubles. As the heating of an armature tends to carbonize and destroy the vitality of the insulation, as soon as this insulation has fallen, a treatment should be given the armature which will again restore the insulating qualities, and the following methods can be used in order to accomplish this result. The armature should be first put in a bake oven, the temperature not being over 120 degs. Fahr. Passing a current through the armature in order to dry it out does not give good results in practice. If there are any leaks or moisture in the armature, it tends to set up internal electrolysis, which again impairs the vitality of the insulation. After the armature has dried in the oven for two or more hours, and while still warm, paint with thin air-drying asphalt compound, P. & B. paint, M. I. C. paint, Sterling varnish or shellac. Trials have to be made on these different compounds to find out which gives the best results with the special insulation used for insulating the armature body and coils. Where there is much paper or cellulose insulation, an asphaltic varnish generally gives the best results; with mica and cloth, varnish or shellac gives the best results. Never use anything but alcohol to mix the shellac; wood naptha or wood alcohol gives very poor results. When using shellac do not have the armature above 90 degs. Fahr. and treat several times. After the final treatment bake the armature for 4 hours at 150 degs. Fahr., bringing the temperature gradually up to this point. The armature should be turned several times during this baking, in order to allow any free solvent to run and dry out. The heads or any covering over the winding should be taken off for this treatment. Of course splines should not be removed.

The above treatment is useless unless the armature is first heated, since, if cold, the treatment will only be superficial, whereas if the armature is hot and then allowed to cool, the insulating compounds will be drawn in and impregnate the whole insulation. A carbonized insulator if impregnated with insulating compounds will break up as a partial conductor.

Flashing at the brushes, due to short, broken or weak brush springs, or short-circuited rheostats, will cause sufficient arcing to burn through the heading of the armature. These heads as a rule do not afford sufficient protection from this source of trouble. A layer of asbestos paper between two layers of canvass on the head will greatly strengthen this weak point. This flashing across from the brush to the winding, causes a bucking of the motor, which, if not cut out immediately, means considerable damage to the armature. Fields are often broken down from this same cause, and a rigorous brush inspection results in reduced motor repairs where the breakdowns are caused by flashing.

The striking of the armature against the field in a toothed armature bends the teeth over and they pierce the insulation on the armature coil. Several types of motors have been designed in which the armature bearing has been too small and improperly proportioned, and it is only by very close inspection that the armature can be kept in proper alignment. The position of the armature should be midway between pole pieces, for if there is any looseness in the bearing, the stronger magnet will pull it towards that pole piece and the direction of the movement of the car will tend to throw it against the rotation of the pinion.

The internal troubles of an armature are generally evident upon external examination, after they have crippled the armature. Flashing at the commutator may be caused by carbon dust on the commutator bead ring or carbonized oil on the commutator surface. There is also a commutator bead ring used which is carbonized when an arc passes over its surface; it has a low resistance and forms a partial conductor. This material should not be used directly in contact or slipped directly over the commutator bars. Several strips of mica should be bound around the commutator bars, and the ring then slipped over these.

Where an armature tests low to ground, this bead ring or commutator ring should be first wiped clean of all carbon dust and oil, and the ground, if caused by leaking over this surface, will sometimes be removed in this way.

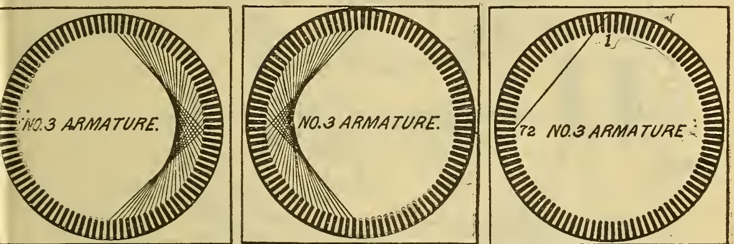
In cases of emergency where an equipment has to run and still there is a ground on the armature which cannot be removed, and the coils are burnt out, a motor can be made to operate (where there are not more than three coils affected), by cutting these coils out entirely and plugging these commutator bars together. This is best done by soldering the ears together or putting in a jumper; sometimes a hole is drilled between the bars and a brass plug driven in. It should always be remembered that where one end of a coil is cut out from a commutator bar, the other end of the coil should also be cut where it connects to the symmetrically located commutator bar. The distance apart of these two commutator bars will depend upon the number of armature coils and the method of winding the armature. The armature should not be allowed to run in this way any longer than is absolutely necessary, since this armature will take more than its share of the load, if worked in parallel with another motor on the equipment, and will lead to excessive heating which will surely destroy the insulation after a short service.

Machine wound coils are largely used, and they are furnished already insulated with two layers of cotton on the wire, and taped with a double layer of oil silk and from 1½ to 2 layers of insulating tape, so that their insulation is amply reinforced at the weak points in windings. The weakest point in an armature body is where the turns leave the slot; if there is any movement at all in the coil, it will wear through or abrade at this point and break down. A combination of mica and fibre paper formed into a strip at least as wide as the band or heading, should be forced in at this point and project outside of the slot at least ⅛ in; the coils should be driven down into the slot and protected from the iron tooth at these points by this strip of insulation. Complete troughs of micanite are sometimes used with good results. Paraffin can be used where these coils slip in hard. After the first layer of winding is on the armature, the insulation between the first and second layers on the commutator end should be several thicknesses of canvas and mica.

DATA ON WESTINGHOUSE MOTORS.

Westinghouse Motor No. 3.—Speed at full load, 300-350 rev. Rated horse-power, 20-25-30. Reduction ratio, 3.45. Gear, 18 teeth on pinion, 62 teeth on gear; 4 poles; 4 field coils; 732.4 turns, total of 4 coils. Size wire 150 x 170 mils square. Armature has 95 slots, 8 conductors per slot; number of bands, 22. Commutator bars,95. Armature bearings : commutator bearing, 1¾ ins. x $4\frac{11}{16}$ ins.; pinion bearing, 2½ ins. x 5½ ins. Weight, 471 lbs. Diameter, 11⅝ ins.; length, 13¾ ins. See Figs. 306 to 308.

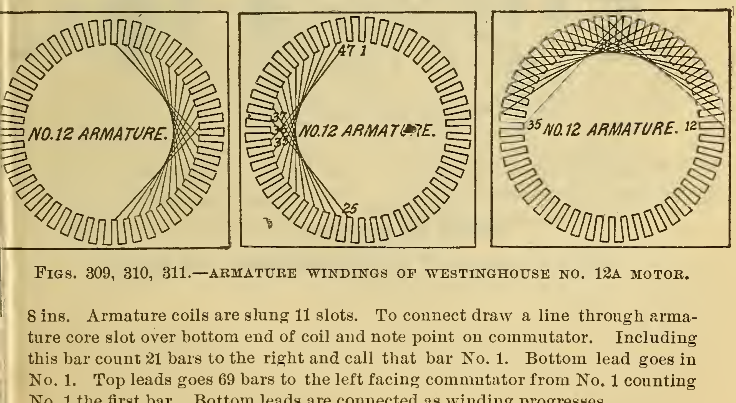
Westinghouse Motor No. 12A.—Speed at full load, 505 to 700 rev. Rated horse-power, 25 to 30. Reduction ratio, 4.86. Gear, 14 teeth on pinion, 68 teeth on gear; 4 poles, 4 field coils; 636.4 turns, total of 4 coils. Armature has 47 slots, 20 conductors per slot; number of bands, 14. Commutator bars, 93.



FIGS. 306, 307, 308.—METHODS OF LAYING ON COILS ON WESTINGHOUSE NO. 3 ARMATURE.

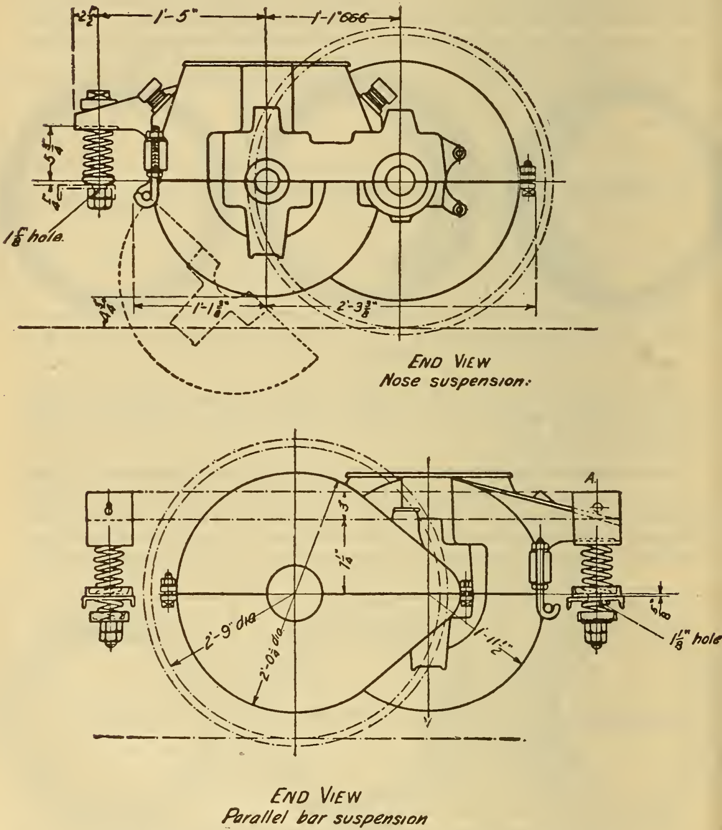
Armature bearing, 2½ ins. x 6 ins. Weight, 360 lbs. Diameter, 11⅝ ins.; length, 7½ ins. See Figs. 309 to 311 for armature windings. For dimensions of this motor see Figs. 312, 313.

Westinghouse Motor No. 38B.—Speed at full load, 500-525 rev. Rated horse-power, 50. Reduction ratio, 4.86. Gear, 14-24 teeth on pinion, 68-58 teeth on gear; 4 poles; 4 field coils; 380 turns, total of 4 coils. Armature has 45 slots, 12 conductors per slot; number of bands, 8. Commutator bars, 135. Armature bearing, 2¾ ins. x 6 ins. Weight, 525 lbs. Diameter, 13⅞ins; length,

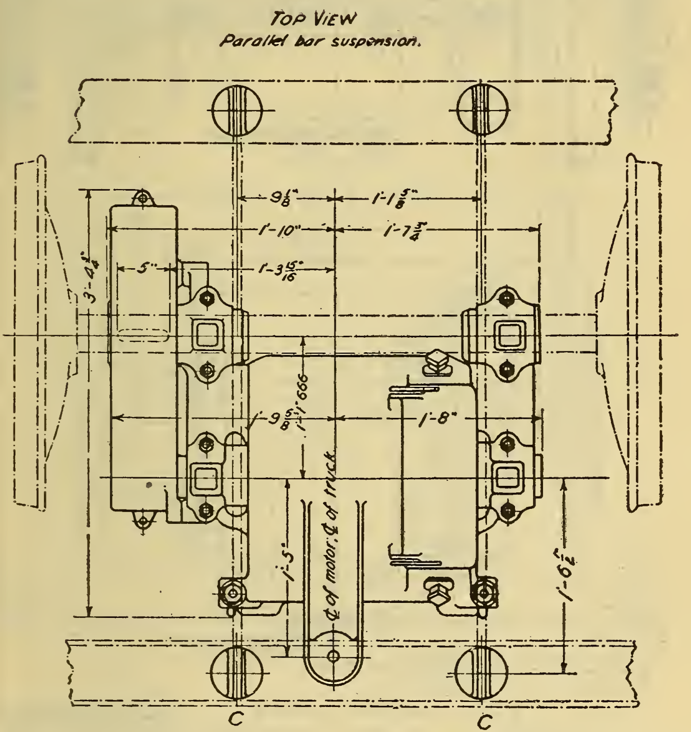


FIGS. 309, 310, 311.—ARMATURE WINDINGS OF WESTINGHOUSE NO. 12A MOTOR.

8 ins. Armature coils are slung 11 slots. To connect draw a line through armature core slot over bottom end of coil and note point on commutator. Including this bar count 21 bars to the right and call that bar No. 1. Bottom lead goes in No. 1. Top leads goes 69 bars to the left facing commutator from No. 1 counting No. 1 the first bar. Bottom leads are connected as winding progresses.



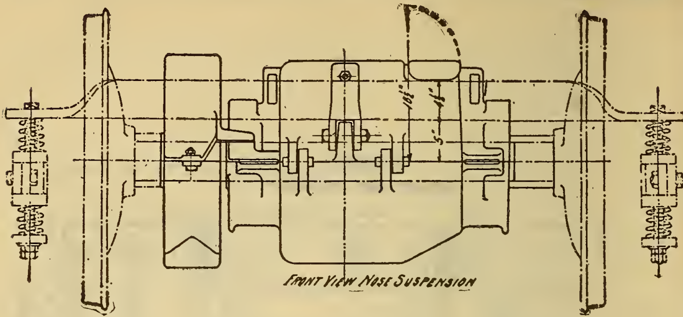
FIGS. 312.—DIMENSIONS OF WESTINGHOUSE NO. 12A MOTOR.

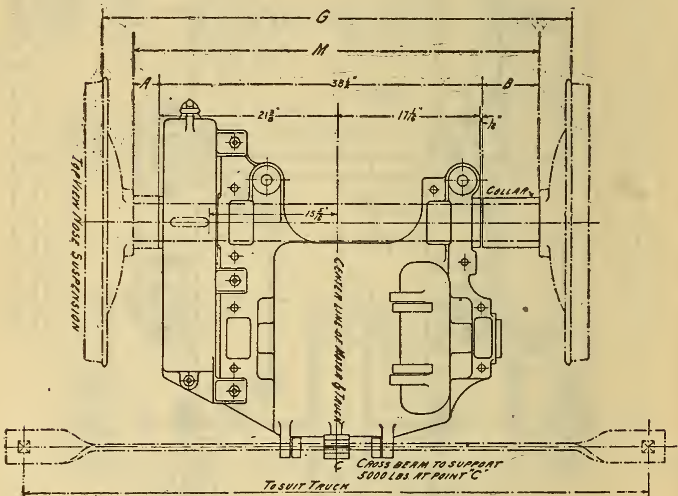


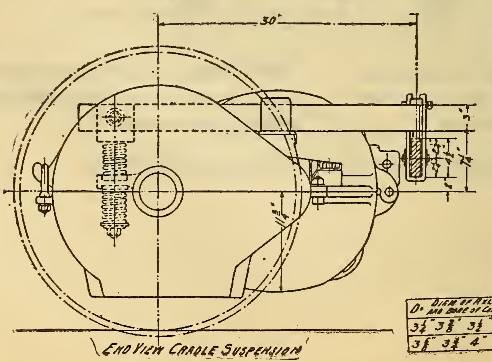
FOR NOSE SUSPENSION
Cross channel bar to support 2500 lbs. at each point marked "B."

FOR PARALLEL BAR SUSPENSION
Cross channel bar to support 1500 lbs. at each point marked "C."

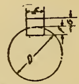
FIG. 313.—DIMENSIONS OF WESTINGHOUSE NO. 12A MOTOR.





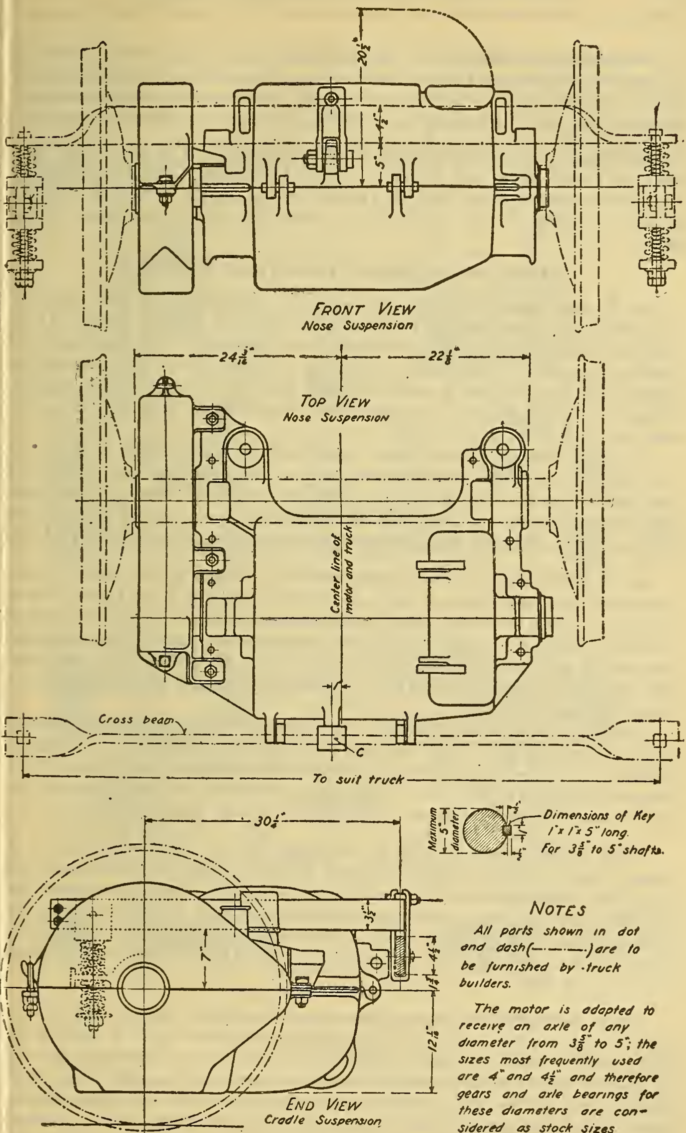


GAUGE OF TRUCK G	DIST. BETW. HUBS M	LENGTH OF COLLAR A	B
4'-8½"	48 15/16"	3 3/32"	7 9/32"
4'-10½"	50 15/16"	4 3/32	8 9/32
5'-0"	52 7/16"	4 27/32"	9 1/32"
5'-2½"	54 15/16"	6 3/32"	10 9/32
5'-4½"	56 15/16"	7 3/32	11 9/32



D = DIAM. OF AXLE AND BORE OF COLLAR	KEY	E	F	G
3¼" 3⅜" 3½"	¾"×¾"×5"	¾"	5/16	¼
3⅝" 3¾" 4"	1"×1"×5"	1"	9/16"	5/16"

Figs. 314, 315, 316.—DIMENSIONS OF WESTINGHOUSE NO. 49 MOTOR.



FIGS. 317, 318, 319.—DIMENSIONS OF WESTINGHOUSE NO. 56 MOTOR.

Westinghouse Motor No. 49.—Reduction ratio, 4.86. Gear, 14 teeth on pinion, 68 teeth on gear; 4 poles; 4 field coils. Armature bearings: commutator bearing, 2¾ ins. x 6 ins.; pinion bearing, 2¾ ins. x 7⅛ ins. Weight, 438 lbs. Diameter, 13⅞ ins.; length, 6½ ins. See Figs. 314 to 316 for sizes of this motor.

Westinghouse Motor No. 56.—Reduction ratio, 4.86 to 3.56. Gear, 14-18 teeth on pinion, 68-64 teeth on gear; 4 poles; 4 field coils. Armature bearings; commutator bearing, 3 ins. x 7½ ins.; pinion bearing, 3¼ ins. x 8⅜ ins. Weight 720 lbs. Diameter, 14 ins.; length, 12 ins. See Figs. 317 to 319 for sizes of this motor.

DATA ON GENERAL ELECTRIC MOTORS.

G. E. 800 Motor.—Rated horse-power, 27. Speed at full load, 530 rev. Reduction ratio, 4.78. Gear, 14 teeth on pinion, 67 teeth on gear; 4 poles; 2 field coils; 203 turns, total of 2 coils. Armature has 105 slots, 8 conductors per slot; number of bands, 5. Commutator bars, 105. Armature bearings: commutator bearing, 2½ ins. x 4½ ins.; pinion bearing, 2½ ins. x 6 ins. Weight, 635 lbs. Diameter of armature, 16 ins.; length, 8 ins. Field wire No. 6 B. & S.; armature wire, No. 10 B. & S.

Armature coils are slung 27 slots. Long leads go to the right 27 bars. To determine bar draw a line through armature core (slot) over top end of coil and note point where it strikes commutator. Including this bar count 27 to the right and call that bar No. 1. The short lead goes into the commutator 53 bars from No. 1 counting to the left facing commutator and counting No. 1 as the first bar.

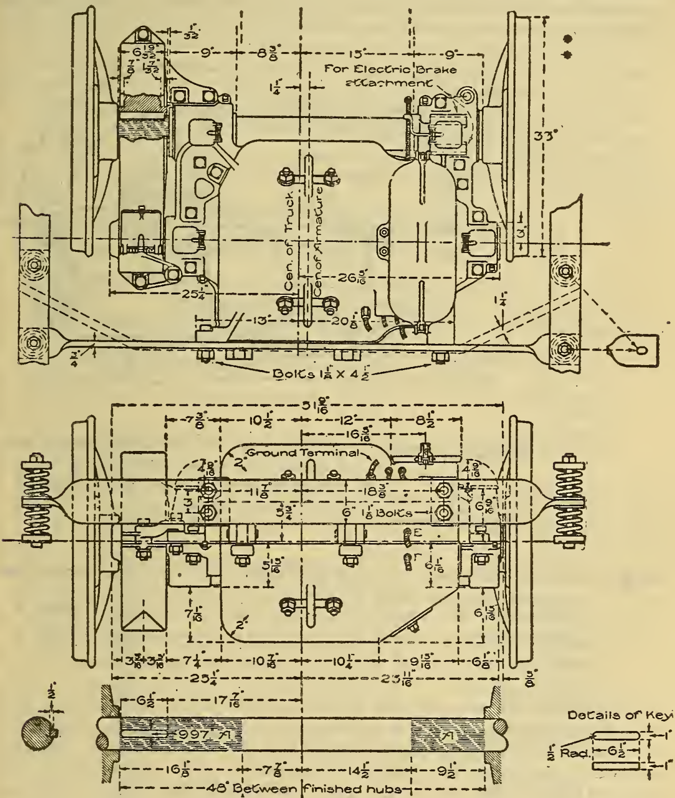
G. E. 1000 Motor.—Rated horse-power 35. Speed at full load, 500 rev. Reduction ratio, 3.94. Gear, 17 teeth on pinion, 67 teeth on gear; 4 poles; 4 field coils; 143.5 turns, total of 4 coils. Armature has 93 slots, 8 conductors per slot; number of bands, 3. Commutator bars, 93. Armature bearings: commutator bearing, 2⅝ ins. x 6⅜ ins; pinion bearing 3 ins. x 8 ins. Weight 578 lbs. Diameter, 14½ ins.; length, 8⅜ ins. Field wire or conductor, No. 4 B. & S.; armature wire or conductor, No. 9 B. & S.

Armature coils ars slung 24 slots. To connect draw a line through armature core (slot) over the top end of coil, and note where the line strikes commutator. Including this bar count 12 bars to the right and designate that bar as No. 1. Connect short lead to No. 1 bar. Long leads go 47 bar to the left facing commutator counting from No. 1 to the left and counting No. 1 bar as the first bar.

G. E. 1200 Motor.—Speed at full load, 260 rev. Reduction ratio, 3.53. Gear, 17 teeth on pinion, 60 teeth on gear; 4 poles; 2 field coils; 198 turns, total of 2 coils. Armature has 105 slots, 8 conductors per slot. Commutator bars, 105. Armature bearings; commutator bearing, 3¼ ins. x 6 ins.; pinion bearing 3¼ ins. x 8 ins. Weight, 963 lbs. Diameter of armature, 16 ins.; length, 13 ins. Field wire, flat .045 ins. x .816 ins; armature wire, No. 8 B. & S. Armature winding same as G. E. 800.

G. E. 2000 Motor.—Rated horse-power, 80. Speed at full load, 706 rev. Reduction ratio, 3.18. Gear, 17 teeth on pinion, 54 teeth on gear; 4 poles; 2 field coils; 84 turns, total of 2 coils. Armature has 141 slots, 2 conductors per slot; number of bands, 9. Commutator bars 141. Armature bearings: commutator bearing, 3¼ ins. x 6 ins.; pinion bearing, 3¼ ins. x 8 ins. Weight, 1450 lbs. Diameter of armature, 18½ ins.; length, 13¼ ins. Field wire, flat 2 ins. x .060 ins.; armature wire, flat .075 ins. x ⅝ in.

G. E. 51 Motor.—Rated horse-power, 27. Speed at full load, 640 rev. Reduction ratio, 1.74. Gear, 31 teeth on pinion, 54 teeth on gear; 4 poles; 4 field coils; 56 turns, total of 4 coils. Armature has 37 slots, 12 conductors per slot; number of bands 6. Commutator bars, 111. Armature bearings: commutator bearing, 3 ins. x 5¾ ins.; pinion bearing, 3¼ ins. x 8¼ ins. Weight, 953 lbs. Diameter of armature, 16 ins.; length, 10.5 ins. Field wire, flat 1¼ ins. x .080 ins.; armature wire, No. 7 B. & S.

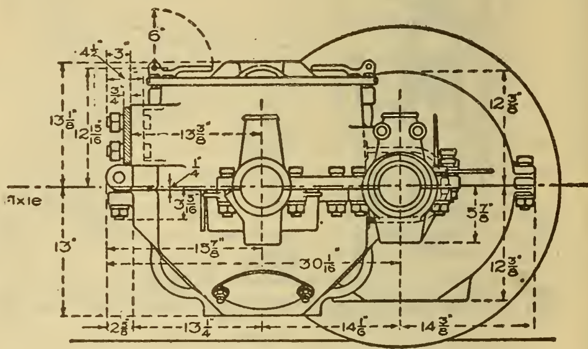


FIGS. 320, 321.—DIMENSIONS OF GENERAL ELECTRIC NO. 57A MOTOR.

G. E. 52 Motor.—Rated horse-power, 52. Speed at full load, 640 rev. Reduction ratio, 4.78. Gear, 14 teeth on pinion, 67 teeth on gear; 4 poles; 4 field coils; 155.5 turns, total of 4 coils. Armature has 29 slots, 24 conductors per slot; number of bands, 5. Commutator bars, 87. Armature bearings: commutator bearing, 2½ ins. x 6 ins; pinion bearing, 2¾ ins. x 7¾ ins. Weight, 357 lbs. Diameter, 11 ins.; length, 9 ins. Field wire, No. 5 B. & S.; armature wire, No. 10 B. & S.

G. E. 57 Motor.—Rated horse-power, 20-25. Speed at full load, 470 rev. Reduction ratio, 3.72. Gear, 18 teeth on pinion, 67 teeth on gear; 4 poles; 4 field coils; 110 turns, total of 4 coils. Armature has 33 slots, 18 conductors per slot; number of bands, 6. Commutator bars, 99. Armature bearings: commutator bearing, $2\frac{7}{8}$ ins. x $6\frac{3}{8}$ ins; pinion bearing, $3\frac{1}{4}$ ins. x $8\frac{3}{4}$ ins. Weight 704 lbs. Diameter of armature, 14 ins.; length, 12 ins. Field wire, flat .035 ins. x $1\frac{5}{16}$ ins. armature wire. No. 9 B. & S; 3 sets of 3 turns each.

Armature coils are slung 9 slots. Bottom leads, which are put in as the winding progresses, are carried 13 bars to the right of core slot that holds bottom



Diam. of Axle A
4"
$4\frac{1}{4}$"
$4\frac{1}{2}$"

Dimensions of unfinished parts are subject to a small variation.

* Weights of pinion and gear change with ratio of gearing.

Weight of Motor complete without axle gear and case		2632	Lbs
"	" Armature and Pinion (16 teeth)	704	"
"	" Axle Gear (69 teeth)	200	"
"	" Gear Case	140	"

Fig. 322.—DIMENSIONS OF GENERAL ELECTRIC NO. 57 MOTOR.

end of coil. To determine the 13th bar draw a line through armature core (slot) close to the left hand side of slot and determine where it strikes the commutator. Including this bar count 13 bars to the right and call that bar No. 1. Top leads go in the commutator 50 bars from No. 1 bar counting to the left facing commutator and counting No. 1 as the first bar. For sizes of this motor see Figs. 320 to 322.

THE CONTROLLER.

The controller used with a single motor gradually places resistances in series with the motor until the latter is directly connected to the trolley wire, when the equipment is up to speed. To change the direction of rotation of the armature a reversing switch is used, which reverses the connections of either the field or the armature, but not of both. To blow out the arc formed on breaking the circuit at the controller, a magnetic field is used with such polarity that it tends to deflect away from the two points on the circuit the arcs thus formed, thus sniffing them out. This apparatus is known as a magnetic blow-out.

With two motors the controller has a more extended combination. Some of these are shown in Fig. 323 and 324. It first places the motors and resistances in series and gradually cuts out the resistance. The next few steps on the controller are known as transition steps, during which the motors are placed in multiple with the resistances again in series with them. The last steps of the controller cut the resistances out leaving the two motors in multiple across the line. In some forms of controller a further connection is made when the motors are in series and multiple only which consists of looping around their fields a resistance, thus reducing the current flow through the field coils, weakening the field in which the armature rotates and in this way increaseing the speed of the equipment.

Figs. 323 and 324 show the motor combinations made by some well-known K and L controllers. The sizes and dimensions of the G. E. railway controllers are given on page 364 and 365. The nomenclature for the different parts of the controller is given on page 363.

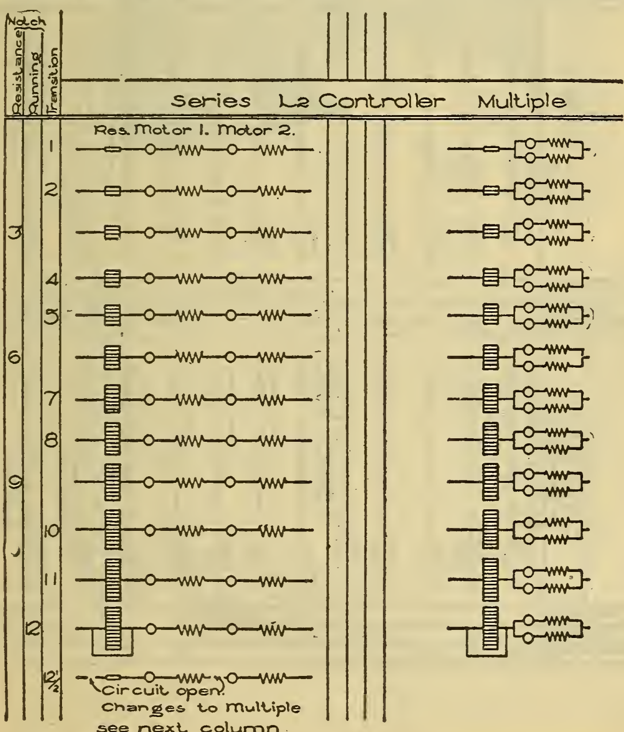


FIG 323.—CIRCUITS SHOWING CONNECTIONS ON L-2 CONTROLLER.

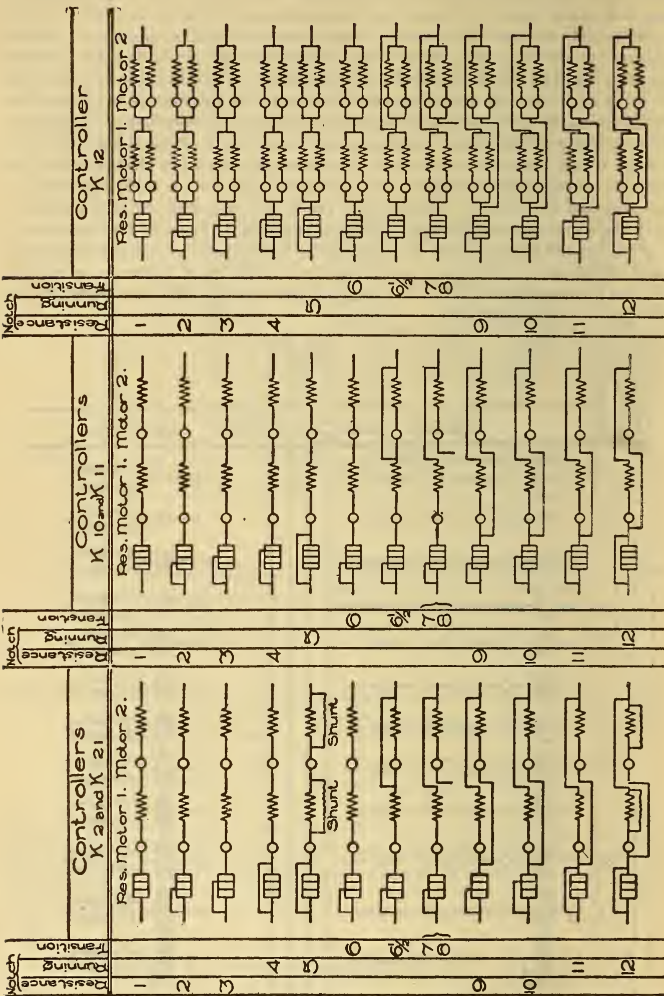


FIG. 324.—CIRCUITS SHOWING CONNECTIONS ON K CONTROLLERS.

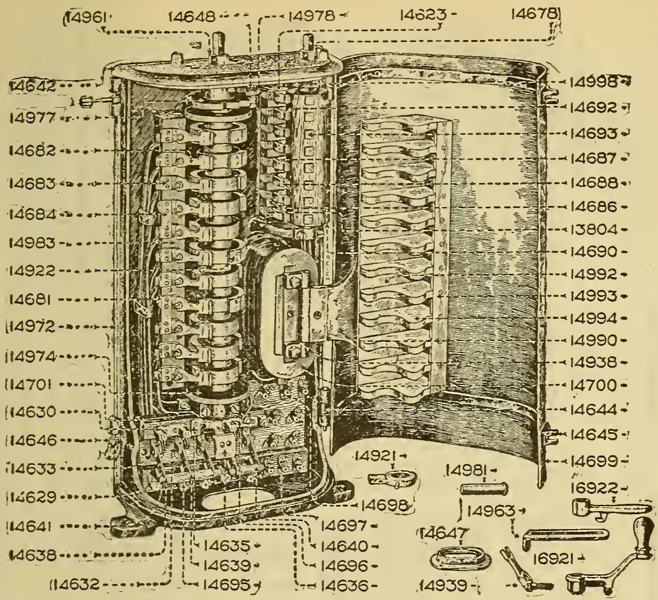


FIG. 325.—SERIES PARALLEL CONTROLLER.

The figures refer to parts shown on accompanying cut.

14,642, cap for top of controller; 14.977, star wheel, with pin, for controlling cylinder (must be fitted); 14,682, contact finger; 14.683, single connection clip: 14,684, double connection clip; 14,983, wood bar for controlling contact board: 14,922, contact tip for controlling cylinder; 14,681, contact base; 14,972, frame, fitted with bearing caps and cap screws for controlling and reversing cylinder shafts; 14,974, insulation disc for controlling cylinder; 14,701, wood base; 14,630, double switch contact; 14.646, hinge bolt, with pin and nut fastening cover to frame; 14,633, fulcrum pillar, with pivot, for two wire connection; 14,629, single switch contact; 14,641, triple switch handle; 14,638, outer switch blade; 14,632, fulcrum pillar, with pivot, for one-wire connection; 14,961, water cap and pointer for controlling cylinder shaft, with set screw; 14,648, lock bolt with pin (used in connection with check lever for reversing cylinder); 14,978, check lever, with roller for controlling cylinder; 14,623, check lever, with roller for reversing cylinder; 14,678. water cap for reversing cylinder shaft, with set screw; 14.635, fulcrum for 14,634; 14,639, inner switch blade; 14,695, single switch contact and binding post; 14.921, safety stop nut, with pin, for controlling cylinder; 14,698, binding post, marked ("T"); 14,697, binding post (except that marked "T"); 14,640. double switch handle; 14,696, single switch contact and long binding post; 14,636, bent cam lever for 14,634; 14.981, safety stop pin for controlling cylinder; 14,963, bracket fastening controller to dasher; 14,647, wire guard; 14,939, cap screw, with wrench attached, fastening pole piece to magnet core; 14.998, star wheel, with pin, for reversing cylinder; 14,692, short contact for reversing cylinder; 14,693, long contact for reversing cylinder; 14,687, contact base; 14,688, contact finger; 14,686, wood bar for reversing contact board; 13.804, double washer for 13,369; 14,690, wood body for reversing cylinder; 14,992, wide strip for arc deflector; 14.993, narrow strip for arc deflector; 14,994, division plate for arc deflector; 14,990, hinge pole piece; 14,938, hinge joint for pole piece; 14,700, magnet spool, with terminal and flexible lead (Form 2); 14,644. hinge joint for cover, with pin and rivets; 14.645, slotted lug for cover, with rivets; 14,699, sheet iron cover (Form 2), complete; 16,922, reversing handle; 16,921, controlling handle.

DIMENSIONS OF CONTROLLERS.—(SEE OPPOSITE PAGE.)

	Type K.												Type L.		
	K	K-2	K-4	K-6	K-7	K-8	K-9	K-10	K-11	K-12	K-13	K-14	L-2	L-3	L-4
A	33 3/16	35 1/16	35 1/16	38 3/4	33 3/16	33 3/16	33 3/16	33 3/16	33 3/16	33 3/16	39	38 7/8	40 7/8	45 1/2	40 7/8
B	7 5/16	7 5/16	7 5/16	8 1/2	7 5/16	7 5/16	7 5/16	7 5/16	7 5/16	7 5/16	10	10	10 7/8	13	10 7/8
C	2 7/8	2 7/8	2 7/8	3 3/4	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	2 7/8	5 3/4	5 3/4	7 3/4	6 1/8	7 3/4
D	4 5/8	4 1/2	4 1/2	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	....	....	....	....	....
E	1	1	1	1	1	1	1	1	1	1	....	....	....	....	....
F	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	....	....	....	....	....
G	41 11/16	43 1/2	43 1/2	47 1/16	42 1/4	42 1/4	42 1/4	42 1/4	42 1/4	42 1/4	46 11/16	46 9/16	48 1/4	53 3/4	48 1/4
H	28 15/16	29 7/8	29 7/8	33 3/16	28 15/16	28 15/16	28 15/16	28 15/16	28 15/16	28 15/16	....	....	....	....	....
K	24 7/16	25 3/8	25 3/8	28 11/16	24 7/16	24 7/16	24 7/16	24 7/16	24 7/16	24 7/16	....	....	....	....	....
L	16 5/8	16 5/8	16 5/8	16 1/2	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	16 5/8	19	22 3/4	25 1/8	28 7/8	25 1/8
M	17 1/2	17 1/2	17 1/2	17 1/16	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	17 1/2	20	23 3/4	27 13/16	29	32 9/16
O	5 1/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	8 3/4	8 3/4	....	5 11/16	....
P	8	8	8	8	8	8	8	8	8	8	9 1/2	9 1/2	9 1/2	13	9 1/2
R	8 3/16	8 3/16	8 3/16	9 1/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	8 3/16	11	11	11 5/8	14	11 5/8
S	....	....	....	....	....	....	....	....	....	....	....	....	18 5/8	....	18 5/8
U	5 1/4	5 1/4	5 1/4	4 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	5 1/4	4	4	....	3 1/4	....
V	7 7/16	7 7/16	7 7/16	6 11/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	7 7/16	10 3/4	10 3/4	....	15 1/8	....
W	6 11/16	6 11/16	6 11/16	5 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	6 11/16	5	8 3/4	....	9	....
X	4 5/16	4 5/16	4 5/16	4 11/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	5 1/2	5 1/2	....	10	....

DIMENSIONS OF CONTROLLERS.—(CONTINUED.)

TYPE B.

	B-A	B-3	B-6	B-7	B-8	B-13	B-16	B-19	B-23	B-24	B-29
A	36 1/16	36 1/16	35 7/8	36 13/16	42	38	38	36	38	38	38 5/16
B	8 1/8	8 1/8	8 3/16	10 1/4	11 1/4	9	9	9 7/16	9	9	9
C	3 11/16	3 11/16	3 3/4	4 3/8	5 3/8	4 1/4	4 1/4	3 13/16	4 1/4	4 1/4	3 3/4
D	4 5/8	4 5/8	4 5/8	......	......	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8	4 5/8
E	1	1	1	......	......	1	1	1	1	1	1
F	3 1/2	3 1/2	3 1/2	......	......	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2	3 1/2
G	44 9/16	44 9/16	44 3/8	45 1/4	50 7/16	46 1/2	46 1/2	44 3/8	46 1/2	46 1/2	46 11/16
H	30 9/16	30 9/16	28 7/8	......	......	30 5/8	30 5/8	29 3/16	30 5/8	30 5/8	30 5/8
K	26 1/16	26 1/16	24 3/8	......	......	26 1/8	26 1/8	24 11/16	26 1/8	26 1/8	26 1/8
L	19	19	25	27 3/8	28 3/8	21 1/2	21 1/2	25	21 1/2	21 1/2	21 1/2
M	19 5/8	19 5/8	25 5/8	28 1/8	29 1/8	22 1/8	22 1/8	25 3/4	22 1/8	22 1/8	22 1/4
O	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	5 3/4	6 3/8
P	9	9	9	9	9	9	9	8	9	9	8
R	8 13/16	8 13/16	8 13/16	11 1/8	12 1/8	9 3/8	9 3/8	9 7/8	9 3/8	9 3/8	9 11/16
U	6 1/2	6 1/2	6 1/2	4 3/8	4 3/8	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2	5 1/2
V	9 5/16	9 5/16	10 5/16	7 3/4	7 3/4	12 7/8	12 7/8	6 5/8	12 7/8	12 7/8	6 5/8
W	6 1/4	6 1/4	9 1/4	6 3/4	6 3/4	5	5	5 13/16	5	5	5 11/16
X	4 7/16	4 7/16	4 7/16	6 5/8	6 5/8	5 5/16	5 5/16	5 1/16	5 5/16	5 5/16	4 7/8
Y	......	......	......	8 3/8	9 3/4	......	......	8 7/16	......	......	5 1/16
Z	......	......	......	8 3/4	8 3/4	......	......	8 3/4	......	......	8 3/4

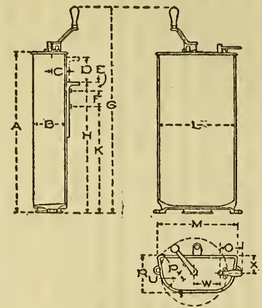


DIAGRAM OF G. E. CONTROLLER, SHOWING DIMENSIONS GIVEN IN ACCOMPANYING TABLES.

CAR WIRING.

The roof wiring includes the running of the main circuit wire from the trolley through both main motor switches, and through a concealed groove in the corner post of the car. The size of this wire is given by the different companies for their motors. The wire is run to a suitable location for connection to the lightning arrester and fuse box, also a lamp circuit of No. 16 B. & S. stranded is tapped to wire the trolley connection on the roof and carried to the fixture outlets and the end left to attach to the ground. Where the wires lie on top of the roof, they should be covered by molding which is well painted to exclude any moisture, especially so where the wires pass through the roof. Additional protection of a piece of canvas under the molding, which has been thoroughly painted with white lead, is necessary at this point. The molding should be firmly screwed down to the roof and well painted. The above wiring should be done, if possible, while the cars are being built.

The floor wiring may be done after the car is completed without injuring the finish when the body and truck dimensions of the car are given. The different motor companies will furnish a made-up cable having the proper number of wires taped together or covered with hose, and of proper length to reach from the controllers to the motors. A hole should be made in the platform under the controllers for the cable to pass through, and in the case of closed cars the cable should pass up again underneath the car seats. In the case of open cars all the wiring is done under the car body. The cables that pass under the platforms should be supported by leather straps attached to the floor or sills. The ground wiring should run under the car floor rather than under the seats.

After the cable is in position the motor taps should project through the sills for attachment to the flexible motor leads just far enough to permit an easy connection, and with as little chance for vibration as possible. The cables should never be bent at a sharp angle. The joints should be well soldered, and in the case of connecting stranded wires together, the strands should be interwoven before soldering; first tape with insulating tape and then put a rubber tape over it to secure the first tape in position. Wherever the wires of the car cross each other a piece of wood should be secured between the wires, and special protection and additional covering should be given the wires where they pass over iron work or are exposed to mud and water.

Wires entering fuse boxes or lightning arresters should be looped down before entering, in order to prevent water running along the wire and into the box. All wires subject to vibration, sucn as those between car bodies and motors, should be of flexible cable, and sufficient slack should be left so that under no condition will any strain be thrown on these wires. In the case of swiveling trucks, more slack will be necessary. As slack gives great opportunity for abrasion, care should be taken to leave only what is absolutely necessary.

THE MOTORMAN.

The old saying, that "Trifles make perfection, but perfection is no trifle," applies to the street railway service as to every other undertaking. It is only by giving the best attention possible to every detail in the complicated system that perfect results are obtainable, both in economy and efficiency of operation. From the general manager to the switchboard tender and the man who fires the boilers, each employee has an important part to play, and it is only by a thorough understanding of his duties that he can render effective service. It is for the purpose of giving a few practical suggestions to the motormen that this section has been compiled, in which no technical terms have been used but such as any person of average intelligence can easily grasp.

The object of chief concern to the motorman is the controller, for, if he can perfectly manage that, he may be said to understand a large part of his work. When the car is standing still, the controlling handle should be at "off" position. If the car is to be taken out of the car house, where it has been standing with the trolley off. put on the trolley wheel and place the handles on the controlling stand.

To start the car, see that the brakes are off, the canopy switches closed ; then move the controller handle to the first notch. After the car is well started, move to the second notch, and after a short time to the third, and so on to the last. Don't stop the handle between notches, and don't move it too slowly. On the other hand, do not move too rapidly from the first notch to the second. Always wait for the car to get up to the speed corresponding to the notch the controller handle is on before going to the next notch, otherwise more current will be used than is necessary.

In shutting off the current the handle may be moved around as rapidly as desired to "off" from whatever position it may happen to be on. When stopping at any point, the reverse lever is sometimes used to make the car go backwards. Never reverse while the car is running, unless to avoid an accident. But if it is absolutely necessary to stop the car quickly, pull the brake on with the right hand and shut off the current with the left at the same time; then, with the right hand free, throw the reverse lever and turn on a very little current. If too much current is turned on, the wheels will lose their adhesion to the rails and spin backwards, which will increase the minmum distance in which the car may be possibly stopped.

Sometimes a very violent stop must be made, when the brakes fail, possibly, or the trolley comes off, in which case reverse and put the controller handle on the highest point of the controller. This causes an interaction between the motors which brings them to a standstill. It may damage the apparatus, however, and should only be used in rare emergencies ; this method is only available when two motors are on the car.

When approaching curves or turnouts the power should be turned off, applying such power upon reaching the curves as may be necessary to carry the car easily around. The conductor should be on the rear platform with the trolley rope in his hand, ready to give the signal in case the trolley jumps the wire, in which case the motorman should move the controller handle to "off" until he is notified to go ahead. The motorman should never stop on curves unless absolutely necessary.

In running down grades, always have the trolley on the wire, the controller handle at "off", and the brake arranged so that it can be applied instantly. Before going down a steep grade slow up the car, and set the brakes gradually. If the wheels slide, loosen the brakes to allow them to get hold of the track; then apply the brakes again. If the brakes then fail, reverse the motors. If, in the meantime, the trolley has left the wire, so that there is no power, reverse and throw the controller handle to the last notch, which will make the car come to a standstill.

In running up heavy grades, get the car up to speed, if possible, before reaching the grade so that it will not require so much current to climb up. If the car is started while on a heavy grade, it will require a very large amount of current. Whether to climb these grades in series or parallel positions is a question on which instructions are given in each individual case. If the wheels slip on the rails, the sand box can often be used to advantage; but always be sure, especially in wet weather, that the sand is dry. Do not use the sand too freely, as you may run short just when it is needed most.

If the power gives out, notice if the other cars experience the same trouble, as it may be due to an open circuit on the line; if so, throw the controller handle to "off," close the lamp circuit and wait until the lamps light up.

If, when the lamps light up, the equipment will not move with the controller handle on the first point, the motorman should first look to see whether his fuse has blown or burnt out; if so, open the head switch, or, better yet, tie down the trolley pole and replace the fuse.

If the fuse has not blown, the rails may be dirty and the car insulated from the rails. In this case have the conductor jam the switch-bar between the wheel and rail, while the motorman starts the car.

In rare instances there is a case of dead rail. A length of wire should be kept in the car where possible, and one end placed on the rail back of the car towards the power station, and one on any exposed part of the iron truck. Always place the end on the rail first, otherwise a shock will be received.

In case, as the car goes along, a peculiar jumping action occurs, known as the bucking of motors, the motor affected should be cut out by means of the motor switches in the controller. Instructions are given the motorman how the motors are cut out on each different type of controller. For remedies for more troublesome accidents see "The Inspector" below.

After bringing the car into the car house have the controller at "off," take off the controller handles, pull down the trolley and tie it a few inches below the trolley wire.

THE INSPECTOR.

Sparking at Commutator.—Natural sparking will be caused by overloading of motor, or by burnt-out fields; by the shifting of brush-holder in street railway motors, by not having the brush-holder yoke so as to be at equal distance from the commutator on the two sides, or where there are several brushes on one arm or holder by their not being in alignment. The most prevalent causes of sparking in street railway motors are weak brush springs, or a brush worn too short to receive pressure from the spring. Since brushes vary in size they sometimes fit tightly in the holder and will produce sparking or flashing when worn away from contact with the commutator. The number of bars apart brushes should be set on any commutator is the total number of commutator bars divided by the number of poles. Subtract from this the number of bars covered by one brush which gives the commutator's bars between brushes. A commutator in proper order should have a dark bronze color, without any biting away of copper at the mica insulation. Where two brushes are used, both should wear down uniformly. No two brushes should be used in the same brush-holder without being separated by a solid dividing piece between them, and with separate springs to each brush, or they will wear a hollow in the center of the commutator surface.

In street car motors with a roughened commutator the brushes are taken out in some cases, and with a two motor equipment this motor is cut out at the controller. A piece of wood provided with a handle (see Fig. 326), and having a curved surface, forms a useful device for smoothing. It is as wide as the commutator, and across the top a clamp to hold sand-paper is screwed down by a screw in the handle. The ends are turned over and securely held. No. 1 or 00 is used as required. While holding this in contact with the commutator the car is run up and down the track until the commutator shows a polish. If the commutator polishing block is made shorter, the commutator can be polished with the motor operating the car. Some companies use a hollow stone made from a medium hard grindstone, hollowed out to fit the commutator surface, instead of sand paper. Emery is objected to for polishing commutators for the reason that it is so sharp that it buries into the copper as a matrix, and in turn grinds the brushes. Commutators that are out of line, or have high or low bars or bad flats, are best repaired by turning in a lathe on centers, taking as light a cut as possible in order to bring the commutator concentric again. Use a diamond pointed tool, and where the cut is rough lubricate the tool with a thick solution of soap and water.

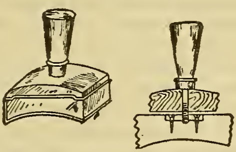


FIG. 326.—COMMUTATOR POLISHER.

It is the practice where the brush wear does not come to the end of the commutator, to leave a small ridge around the commutator at the end next the bearing to further prevent flashing to commutator by oil and carbon dust adhering to the insulating ring at the end of the commutator. A bluish oxide on a commutator shows excessive heating, and the cause should be located.

The commutator will show a bar burnt lower than the adjacent commutator bars when there is a short circuit between adjacent windings connected to that bar, the biting into the commutator will continue back in the direction of rotation. Where this condition is allowed to continue the commutator will come in hot, and the contact surfaces of the brushes will be black and scarred when they should have a bright plumbago appearance. For locating trouble see armature tests.

Commutators, with every other bar blackened, are found in certain types of winding used on railway motors where there are practically two separate windings side by side connecting to alternate commutator bars, and the blackening of every alternate bar is caused generally by a greater difference of potential between adjacent bars under commutation. An open lead to a commutator bar causes flashing when that bar passes under the brushes. An open coil on an armature will show a bad bar even where this coil is connected in around the armature. The equipment continues to operate until the flashing becomes so bad as to break the commutator to ground, or burn through the head of the armature. For this reason armatures are now headed with several layers of asbestos paper under the canvas cover to prevent flashing to ground before the inspector discovers the trouble. The grounding of the armature turns produces a short circuit between the trolley wire and rail, which, under this condition, has a sudden braking action, commonly known as "bucking." When this happens the motor is cut out at the controller and the equipment operated on one motor until it gets to the repair shop.

The efficiency of the inspector can be readily determined by an examination of the commutators on the equipments he has in charge, allowance being made for some motors which require great care to keep the commutators in good shape, Poor potential delivery and dirty tracks also increase the current flow through the motors, heating and burning the commutator surface, which should be glazed. There is a class of dull, steady sparking which leaves dirty black commutators, which is generally attributed to too soft or poor brushes. In new equipments where the mica segments of the commutator have been built up with too much shellac, the heating of the commutator works it out, also causing it to carbonize on the surfaces of the commutator. This will continue until all surplus shellac has worked out. Commutators afflicted with this trouble will show ridges of shellac forced out over the mica insulation between bars. In the morning when the commutator has cooled down, only two or three bars will occasionally show it, especially where the commutator has been repaired and shellac used too liberally in the mica insulation between the new bars. (For proper construction see repair shop practices). Too soft a brush will produce the same effect on the commutator surface but on feeling the surface with the thumb nail slight ridges of mica will be felt between the bars. Try the brush with a knifeblade ; a brush should not be shaved nor penetrated, if the brush is of the proper hardness and the carbon should come off in small granular pieces. This is also true of a brush that is too hard. A hard brush will give with regular brush tension a bright

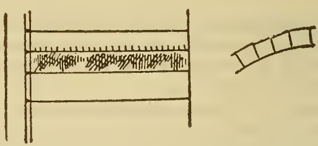


FIG. 327.—EXAMPLES OF COMMUTATOR WEAR.

metal and splintered torn surface to the commutator ; and if the brush is uniformly too hard, signs of copper dust will be seen around the interior of the motor case. If rings of bright copper show around the commutator the brush may have hard spots ; in this case take out the brushes and see if the contact surface shows a corresponding bright spot ; if this spot is found to be harder than the adjacent carbon by penetrating with point of a knife, the trouble is located. A commutator without lubrication will show the same surface as that produced by too hard a brush. Use the best quality of vaselene on a small rag, and use sparingly. Oil is used, and, in some cases, axle grease, for labor saving reasons but not to the best interests of the commutator. A brush that is too hard but of uniform density, as well as brushes that squeak, can be improved by dropping them in hot paraffin; but be sure and heat the brush just before dipping, otherwise the treatment will be superficial. Hot, heavy lubricating mineral oil is also used instead of the paraffin.

It is the custom on some roads for the inspector to change brushes every night on all motors, which insures the inspection of every motor. Brush inspection will show a number of things. A brush that shows pitting on its side (see Fig. 327) indicates bad contact with a weak brush spring, requiring the brush to receive current from the sides of the holder and chattering and arcing between the holder sides and the brush ; a place broken out of the brush where the brush spring rests shows a weakness and a variation here, causing arcing and wearing away of the brush. The commutator contact surfaces of the brush which show a ridge down their length, on both sides of which is a commutator surface, indicates a brush too narrow for the brush holder, as the commutator has worn it to one surface in going in one direction and made another surface in going in the opposite direction due to the change in position of the brush with the movement of the commutator. A brush with burnt corners indicates sparking at the commutator; a brush tapering toward the contact surface, as shown, indicates excessive heating of the commutator or brush due to poor contacts. Brush springs may give good results until they become heated from some cause, when they lose their elasticity. Phosphor bronze springs show the least effect from this cause.

SECTION IX.—THE OPERATION.

Schedule and Speeds.—It is usual to lay out schedules on cross-section paper, taking the longitudinal ordinates for the distances, and the verticals for the time, as shown in Fig. 328. In this way the routes for cars can be obtained, and their crossing points determined. This method is also used for locating the position of switches in single track construction.

In the matter of speeds, the grades and the time consumed on grades is an important element in laying out switching points, or intersecting points, for the cars. Data regarding this can be found under "Line Construction," or the grades

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Number of Revolutions Per Mile for Driving Wheels of Different Diameters.

Diameter of Wheel.	Revolutions per Mile.	Diameter of Wheel	Revolutions per Mile.
18 ins	1,116	36 ins	558
20 "	1,005	38 "	529
22 "	914	40 "	502
23 "	874	42 "	480
24 "	837	44 "	457
26 "	773	46 "	437
28 "	718	48 "	420
30 "	672	50 "	402
32 "	628	60 "	336
33 "	609	72 "	279

Speed of Electric Cars.

1 mile per hour.	88 feet per minute.	1.466 feet per second.
2 " " "	176 " " "	2.933 " " "
3 " " "	264 " " "	4.4 " " "
4 " " "	352 " " "	5.866 " " "
5 " " "	440 " " "	7.333 " " "
6 " " "	528 " " "	8.8 " " "
7 " " "	616 " " "	10.266 " " "
8 " " "	704 " " "	11.733 " " "
9 " " "	792 " "	13.2 " " "
10 " " "	880 " "	14.666 " " "
11 " " "	968 " "	16.133 " " "
12 " " "	1056 " "	17.6 " " "
13 " " "	1144 " " "	19.066 " " "
14 " " "	1232 " "	20.533 " " "
15 " " "	1320 "	22. " " "
20 " " "	1760 " " "	29.333 " " "
25 " " "	2200 " " "	36.666 " " "
30 " " "	2640 " " "	43.998 " " "
35 " " "	3080 " " "	51.331 " " "
40 " " "	3520 " " "	58.666 " " "
45 " " "	3960 " " "	65.997 " " "
50 " " "	4400 " " "	73.332 " " "
55 " " "	4840 " " "	80.663 " " "
60 " " "	5280 " " "	87.996 " " "

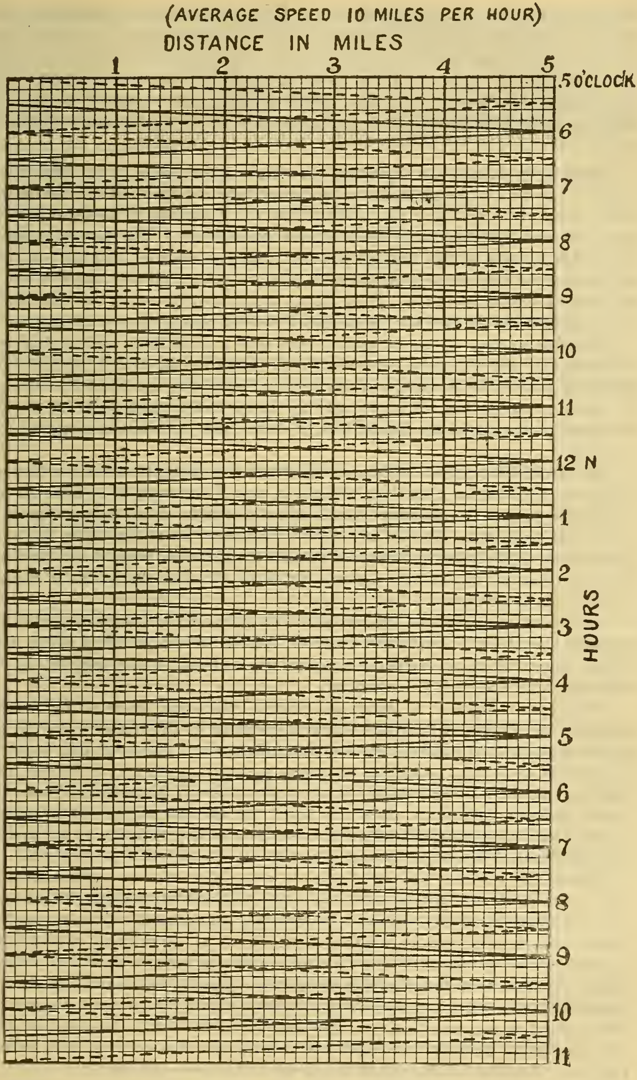


FIG. 328.—SCHEDULE DIAGRAM.

and speeds maintained by equipments; or tests can be made on equivalent equipments in order to find the grade constants. It will be found by testing a car on several different grades that a relation can be established between the speed obtained and the square of rise in feet per second of the car body which will be approximately a constant and can be applied to determine speeds on any other grades. The switching points will not be altered by increasing or decreasing the speed of all equipments, if their grade constants are the same.

Signal Systems.—In signaling on single track roads, it is important, in order not to delay the schedule, that a car arriving at a turn-out can maintain the block ahead clear, and clear the block behind it. A number of methods have been used for this purpose, both manual and mechanical. The principal manual method is known as the Ramsey System. This consists of a signal box at each turn-out, and a single line wire between the turn-outs, with two lamps in one box and three lamps in the other. Each signal box is provided with two handles, one for the block ahead and one for the block behind, which throws the lamps either to ground or to line. It can be readily seen that a motorman, on arriving at the turn-out, can cut the lamps out behind it by throwing the switch to ground, or to the same polarity as the switch at the turn-out back of it, and block the line ahead by throwing the switch so as to light the lamps in the signal box. If the lamps are already lighted in the signal box, it shows that the section ahead is already blocked.

To introduce a signal system of this character on a railroad is a safeguard in operation, and also has great legal weight in case of accident, as it shows an intention on the part of the operator to maintain a system of safety devices for the prevention of collisions. Several law suits for damages occurring where this system has been in vogue have been decided against the plaintiff, since it was shown that the motorman ran against his signals and took chances, the plaintiff being the employee in these cases.

The merit of a manual system is that its operation is always inspected. The rules for operating the road with a manual system should include a clause requiring the reporting of any inoperative signal on the road, so that they will be maintained by a rigid system of inspection.

There are a number of automatic signals which are operated by the trolley throwing the switch, or auxiliary contacts operated by the trolley wheel, to block the road ahead and unblock the road behind the car. These are now being tried extensively on several roads, but in steam railroad practice it is found that in order to ensure reliable results signal systems should be under manual control. Steam railroad experience does not point out the possibility of an automatic device being always reliable, and it is subject to the criticism of all automatic devices that their failure to operate is not observed until after an accident.

Telephone systems have been used in connection with the single track road. The telephone system can be installed, with telephone boxes along the route, generally at the point of turn-out, and the selective system used. Another method is to run two parallel telephone wires along the road connecting the telephone to these wires by means of double hooks, either one hook above the other or a double-pronged hook introduced between the two telephone wires. In these systems the double return should always be used in order to cut out induction; and where there is any trouble from this cause, the wire should be transposed every thousand feet. Hard-drawn copper wire makes the best wire for this construction, and, if covered, it should be weather-proof, double-braided.

Examination of the Motormen.—In examining the motormen for proficiency, special questions should be asked to draw out the emergency methods in use on the road, especially the use of the motors as brakes and when to reverse them. Questions should be asked bearing on points of the road where special attention is required at crossings or where there are special grades to be descended. The following list of questions give those generally used for examination of the motormen:

Having been assigned a car by the foreman of your division, what should be your first duty before taking the same out of the shed?

Who is supposed to have charge of the car?

What are your duties as motorman from the time you take charge of the car until the time you turn the same in, or deliver the car to your relief man?

What are your duties with reference to running over railroad crossings, frogs and switches?

How would you cross railroad crossings, cross-overs, frogs and switches (with the brake set or released)?

What are your duties with reference to handling your car on a down grade?

In running through water what would be the most advantageous method in which to operate the motors?

What are your duties in case your car gets beyond your control in going down a grade?

In case your car wheels slip in making a grade, what method should you apply to obviate same?

What are your duties respecting starting up in case power is shut off?

Under what circumstances are you permitted to reverse your motors?

In case it becomes necessary to reverse the motors, what is your first duty?

In what manner would you replace a fuse?

In case a second fuse blows on being put in, what is your duty?

If a controller acts badly, or other electrical troubles present themselves and either motor becomes uncontrollable, what means would you take to ascertain or locate same?

What are your duties in respect to occupation of your time while the car is on the stand?

What would you do in case your controller becomes unmanageable with the current on and set, and you are not able to turn cylinder to a backward or forward position?

Where are the contact switches located for the purpose of cutting out motors on various types of controllers?

To what extent is the motorman responsible for the operation of the car?

Under what circumstances are you permitted to pass persons desiring to board your car.

In passing persons desiring to board your car, what is your duty?

When approaching a car on opposite track that has been brought to a stop, what is your duty?

Why should you reduce the speed of car on approaching a switch point?

Why should the car clear the cross street before bringing the same to a stop?

Should your car be derailed or from any cause blockade the crossing of a steam railroad, what would be your first duty?

Why should you ring the gong when a vehicle is ahead of your car and along side of the track?

What do you consider the most economical method of operating the controller handle?

Explain the path of the current from the time of leaving the generator at the power house to its return thereto.

Why should the trolley never be pulled down whilst the current is applied?

Under what circumstances would you operate your car faster than time points named on time table?

In what condition must your car be left in the car shed?

What is your duty should you find the trolley wire down?

Do you consider it more important to get away as quickly as possible in the event of accidents in order to maintain your car on time, or to remain and render all assistance possible?

Before bringing the car to a stop on an up grade with a slippery rail, when would you begin dropping sand?

Before making a stop on slippery rail, how should sand be used to prevent flat wheels?

Should sand be used on a dry rail?

Should sand be used on a clean, wet rail?

Can a car be brought to a stop in the same distance under all conditions of the rail?

In what distance would you bring your car to a stop on a level, or slightly down grade, car being operated at a rate of 10 miles per hour, condition of track dry, and rail clean?

What is your duty with respect to the rail ahead of your car?

In case a car does not start after stopping on a dirty rail, what means would you take in overcoming same?

In what position should your controller handle be with respect to the motors, running down grade?

If any electrical trouble presents itself with the motors and then cannot be controlled by the controller, what effort would you put forth in checking same?

In what manner should you handle your controller in building up the motors to full speed?

What are your duties with reference to brakes before bringing up the motors to full speed?

What is your duty to avoid further destruction when a ring of fire passing around a commutator presents itself?

Name the two chief requirements of motormen?

Why should a sharp lookout be maintained at all times on the rail when the car is in motion?

What tools and appliances should motormen have on the car at all times?

What are the bell signals?

Why are motormen and conductors not allowed to enter a car in the car shed other than the car assigned to them?

The Handling of the Controller.—The question of the proper handling of the controller is one in which grades, the weight of equipment, motors and controller, all enter. It is the usual practice to instruct motormen to handle their controller, so as to get the equipment up to full speed in a certain time; but they should be fully instructed to realize the difference between the time when they are operating near the power station, or at the end of the line, where the voltage drop is greater. In this case the acceleration is slower, and to turn the controller on too fast will increase the drop on the line and decrease the acceleration of the motor.

In climbing grades the question arises whether the motor should be in multiple or in series. This depends largely on the location of the car with respect to the potential delivery to the trolley at this point. If the voltage drop is considerable, with the motors in multiple, the series position will be fonnd more economical, and the available energy for the equipment greater. It has been proven beyond a doubt that the proper handling of the controller will save as much as 20 per cent. in the coal bill. The curves (Fig. 329) herewith show some data obtained

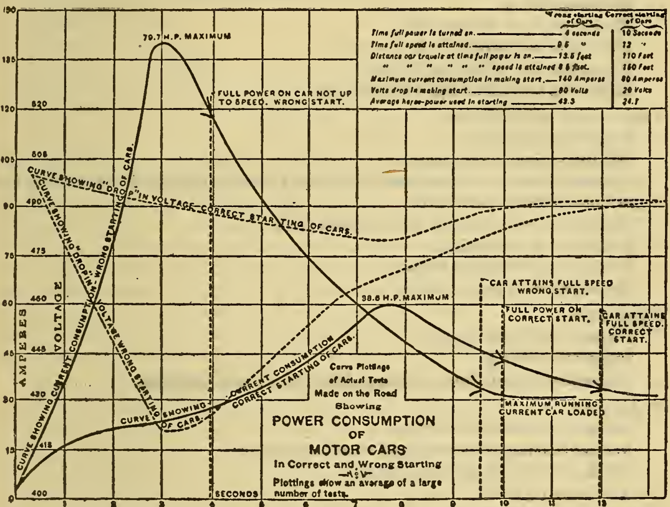


FIG. 329.—CURVES SHOWING ADVANTAGE OF USING CONTROLLER CORRECTLY.

from the Chicago Street Railway, showing the difference in power consumption between a rapid start and a slow start.

Repair Shop Operation.—On many roads the labor in the repair shop has been put on a piece-work basis, and improvements in the cost of maintenance have been obtained by this method of working. The following division has been used by a large repair shop, a price being fixed for each operation. These prices are, for obvious reasons, omitted.

Piece Work Price List for Motor Shop.

CONTROLLERS.

General overhauling includes

Taking out and replacing drnm.

Taking out and replacing wipers (II).

Taking out and replacing springs (II).

Taking out and replacing caps.

Straightening bent cover.

Replacing worn out handles.

Blowing out and inspection of connections in controller, canopy-switch, fuse box and cut-out box.

Exchange drum.

Exchange reverse.

Exchange top (cast iron).

Exchange pawl (in addition to price of exchange drum).

Exchange foot (in addition to price of exchange back).

Exchange back.

Exchange blow magnet coil.

Exchange and fitting broken cover.

Replacing and adjusting wiper.

Replacing and adjusting back-spring.

ARMATURES AND FIELDS.

Replacing armature.

Replacing field coils (each).

Replacing and adjusting brush holder and brushes (included in replacing and inspecting armature clearance).

Replacing and adjusting brush holder yoke.

Replacing brush spring.

Replacing connecting board.

Replacing dust pan or cover.

INSPECTION.

Inspecting wheels (each).

Inspecting trolley.

Inspection of armature clearance, blowing out and painting.

BEARINGS.

Replacing armature bearings.

Fitting bearings on exchanged armature (each).

Fitting axle bearings (new, each).

Axle bearing wick.

TROLLEY.

Replacing worn out wheel and spindle.

Replacing worn out rope.

Replacing pole.

Straightening pole.

Replacing base.

Replacing canopy switch.

Replacing canopy switch handle.

Replacing fuse box.

Replacing fuse box plug.

Replacing cut-out box.

Replacing cut-out box plug.

Replacing three light cluster and lamps.

Replacing single socket and lamp.

Replacing lamp switch and plug.

Replacing pinion (arm in place).

Replacing gear (under car).

One-half gear case taken down and replaced (included in inspecting armature clearance.)

Replacing gear pan (whole).

Putting gear on axle when removing from car.

Miscellaneous Electric.

Replacing motor.
Replacing motor frame.
Making screw connection.
Making soldered connection.
Replacing diverter.
Replacing diverter spool.
Cables (under car).
Stripping frame.
Assembling frame.
Cleaning and painting.

Replacing motor with motor lift (as distinguished from same operation, replacing motor, performed with crane).

Equipment Records.—There are a number of methods of keeping equipment records. Some roads have a card catalogue, each card representing a car between certain dates, on which are printed the different car parts, with blanks left for remarks for the date and character of repairs. From these dates can be computed the life of the car wheels, trolley wheels, controllers and motors. This card can be made as large as 6 ins. x 8 ins., and on the bottom of it are remarks with room for dates when the car came into the repair shop. The mileage of the car is also entered. In this way a complete record of the equipment is obtained, from which can be computed the cost per year for repairs on the car. From these records the cost of maintenance for the different types of equipments, including trucks, motors, trolley stands and wheels, and controllers, can also be determined.

Power Station Records.—If careful data is kept on the power station operation, which includes the item of coal burnt per day and (if it is found economical to divide this to shifts) of coal burnt on each shift, the watts produced for each shift and the water evaporated can be determined. For the purpose of finding the water evaporated, it is well to have an individual water meter for each set of boilers as well as the main meter, to be read for each shift. From this data of the individual meters, and from the effective heating surface the equivalent evaporative efficiency of the boilers can be found. If their cleaning has been neglected it can be ascertained from these individual water meter records.

In regard to the generators it has been customary in large units to have a wattmeter for each machine, in order that the output for each unit per day can be determined. Where there is any difference in the character of the units, by comparing tests (covering a period of a number of days) the efficiency of these different units can be discovered, with respect to the pounds of water and watts output. By carefully noting these records and laying them out carefully in curve diagrams, very often leaky valves or undue frictions can be discovered. A more extensive record form is given on page 84, under "Boiler Room Tests."

Cost of Power.—In the purchase of power by a railway, there are two methods employed: one, by the car mile, and one by the kilowatt hour. The car mile basis is generally figured on an equivalent of 1.2 to 1.8 kilowatt hours to a car mile. The cost of power production for small roads is generally estimated on the basis of a car day, as the rate per car mile to cover the fixed charges against a small power production of this kind would be too high.

In heating, the heating current is taken from 15 per cent to 20 per cent in excess of the operating current. The car basis is fixed on a single truck, standard car body of the type used for the road. It is found that a double truck car does not increase the watts per car mile, within a car-body weight not exceeding three tons, over the single-truck car-body weight.

Lighting is generally included under the car mile basis. On the car mile basis the line losses and ground return losses are against the power producer. On the kilowatt hour basis the line losses, or drops external to the equipment, increase the kilowatts per car mile in two ways; one, by the actual line losses and the other by the inefficiency of the equipment, due to low potentials in equipment operation. On the kilowatt hour basis more copper and better bonding will often show a lucrative investment, but on the car mile basis it does not affect the cost of operation.

Electric and air brakes, both increase the consumption per car mile, the electric brake from using the motor at high temperatures, which tends to increase the C^2 R losses, and the axle driven and electric air brake, on account of the consumption of power for the compression of air.

Charges for power can only be fixed when the conditions are known, which involve the number of equipments operated, the character of track, line drops, and power station investment necessary to maintain the potential on the line.

Appendix I.—Storage Batteries and Boosters.

THE STORAGE BATTERY.

The storage battery in railway work has several important functions. Among the advantages obtained from its use are the relief of overloads, a greater economy of steam in the engine and the saving of copper by the installation of storage battery substations.

It is often desirable for the relief of overloads to install a storage battery on roads having short heavy grades, especially where a number of equipments mount the grade at the same time. This happens when the situation of the center of population is in a valley and the surrounding suburbs are on the hills. Among the first storage battery installations of this class of work was one made in Easton, Pa., where this condition was very marked, the town of Easton lying at the bottom of hills and all the railways having to mount a grade. As the cars met in the town square near the lowest part they all had to mount the grade simultaneously, bringing the average load of 500 amps. up to 1200 amps. for five minutes. A storage battery was installed, which reduced the overload on the engine, and made it possible to shut down several of the units which were operating only for this five-minute demand; and the steam economy, operation and regulation of the station were all improved.

The losses in an engine only partly loaded are large and to run an engine nearer its maximum load increases rapidly the efficiency of the units, for the battery can charge and discharge by means of the regulating booster and maintain the line potential, the battery making up the deficiency of the generator and charging when the generator is below its normal output. The economy of steam in the engine naturally follows the averaging of the load on the dynamos. The cost of a storage battery investment should be figured as follows: Ascertain the coal saved on account of increased economy and the interest on the investment on the engine to do equivalent work, the oil and depreciation on the engine plant being also included. These items collectively should equal the interest on the cost of the storage battery; its depreciation should be taken at about 10 per cent for railway work, especially where heavy demands are to be encountered, and maintenance should also be charged against the battery. It is fair to assume that the storage battery is profitable when its cost is equal to the cost of an engine plant, for the advantages it offers of regulation and the ability to shut down the steam plant, and the lighting of the car houses, when no cars are in operation, are in its favor.

Where the storage battery is used for the saving of copper, the terms entering into the calculation of the economy are cost of copper and the interest charged against this investment against which should be placed the cost of battery installation and its depreciation. A battery installed for copper economy will only show a profit when the battery is located in a substation at a distant point from the station. The economy in transmission would be the cost of the watts lost for the load delivered per annum over a copper distributing system sufficient to give proper potential delivery to the equipment, less the cost of watts lost for charging through the transmission line. The difference between these two transmission

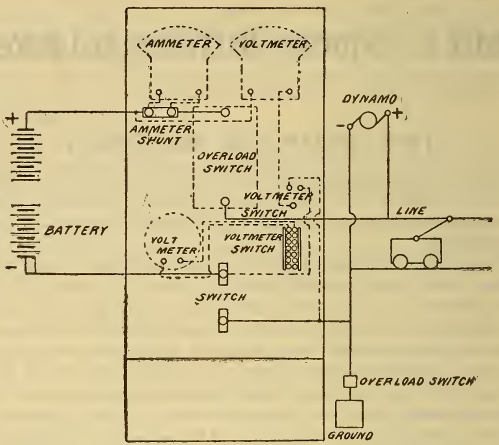


FIG. 330.—SWITCHBOARD CONNECTIONS OF STORAGE BATTERY TO RAILWAY WITHOUT BOOSTER.

efficiencies should make a profitable showing in favor of the storage battery installation.

The battery should be connected together by lead terminals burnt to leaded bus bars, and all copper bus bar work should be lead-coated. Where copper bus bars are clamped together it is advisable to amalgamate the surfaces in contact and draw up by bolts also lead coated.

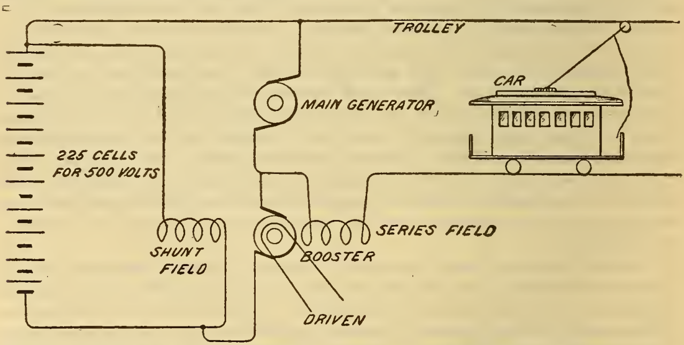


FIG. 331.—DIAGRAM SHOWING CONNECTIONS OF DIFFERENTIAL BOOSTER AND STORAGE BATTERY.

In regard to the switchboard connections Fig. 330 shows the method of connecting the storage battery across the railway generator. In order to regulate properly for the variations of load that occur on the railway generator a booster is connected as shown in Fig. 331. Here the booster is so adjusted that it charges when the generator is above a fixed potential, and discharges when the potential falls below it. The booster has a series field through which the main battery current flows; opposed to this field is a shunt field which works differentially against the series field, so that this booster compensates for the high potential required in charging and the low potential of discharge.

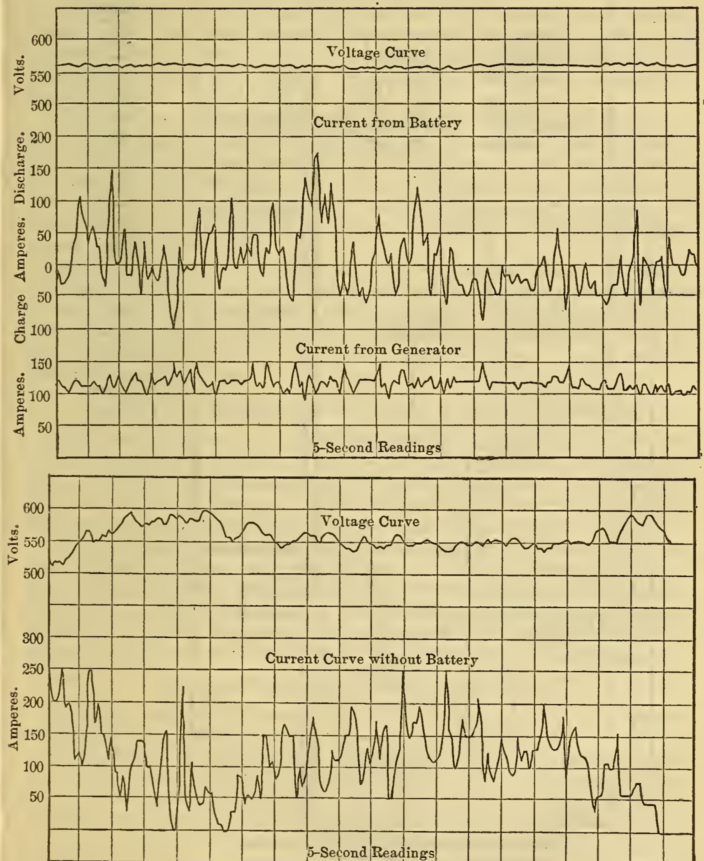


FIG. 332.—EFFECT ON RAILWAY LOADS OF STORAGE BATTERY.

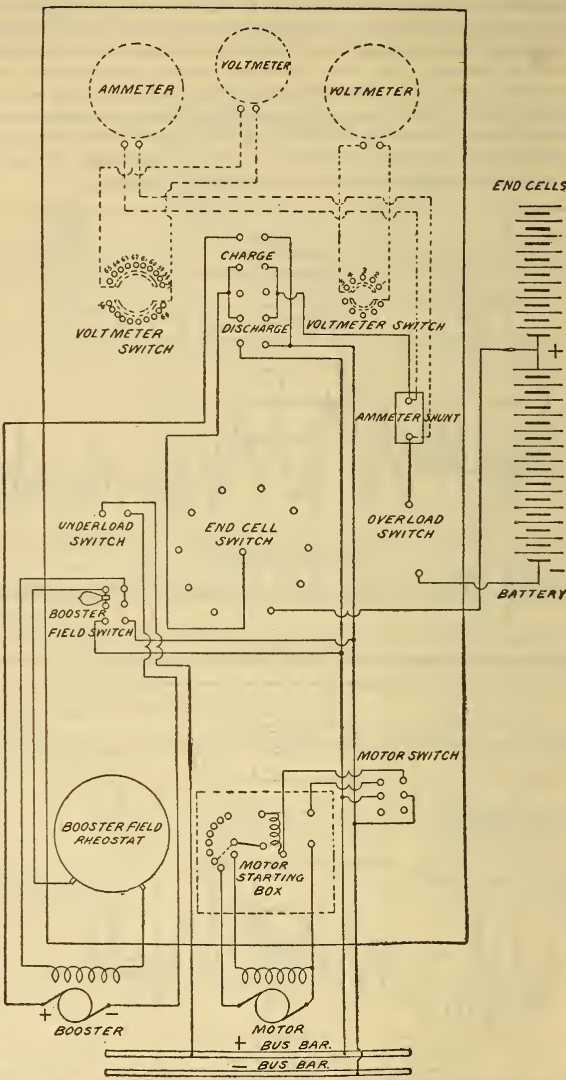


FIG. 333.—SWITCHBOARD CONNECTIONS FOR STORAGE BATTERY, BOOSTER AND GENERATOR.

The curve, Fig. 332, shows the effect on the generator operating in multiple with a booster and storage battery, the compensation for the fluctuation of current demand and also the fluctuations on the engine and generator alone.

Fig. 333 shows the switchboard connections and arrangement of instruments and circuit breakers; it has cell regulation which is not now used in street railway work, the differential booster automatically regulating the charging and discharging of the battery. The booster is preferably driven by a 500-volt motor coupled direct, but may be belted or direct-connected to an engine.

TYPES OF BATTERIES.

There are several different methods employed in the construction of a storage battery. One is the paste method, which is used by the Chloride Accumulator Company. Here a sheet of lead has on its surface small rectangular cells into which is forced the active material. This battery by charging and discharging is readily "formed" for use.

Another type of storage battery which is used in railway work is manufac tured by the Gould Storage Battery Company. In it a plain sheet of lead is grooved by rotary knives so that the lead is forced up between the knives and form ribs and corresponding grooves. These ribs vary in width from .008 to .024 of an inch. There are about 450 sq. ins. active surface per pound of plate, and 186 sq. ins. per cubic inch, while the ratio of the contact-surfaces to superficial area is as great as 17½ to 1.

The active material is formed in the interstices of these ribs by electrolytic processes. From tests on these plates it is shown that they are capable of maintaining a high electro-motive force with discharges at high rates, which is an advantage to be considered in railway work. The plates for railway work are 15½ ins. x 15½ ins. divided into 16 ribbed plates which are formed out of a homogeneous sheet of lead.

DATA ON STORAGE BATTERY INSTALLATIONS.

The Buffalo Railway Company, Buffalo, N. Y.: Capacity of battery, 1200 hp-hours, 250 amps.; consists of 270 cells all in series, with 41 plates to each cell, the size of the plates being 15½ ins. x 15½ ins. The positive plate weighs 24 lbs., the negative, 16 lbs. each. Outside dimension of tank, 59⅞ ins. x 21½ x 24¾ ins., with room in tanks to increase the capacity two-thirds.

The Lansing Street Railway Company, Lansing, Mich.: 240 cells of 9 plates each, 10½ ins. x 10½ ins., and room in jars for 13 plates. Capacity, 320 amp.-hours at 8 hour discharge rate. This battery was used at the end of the line, and will run from about 25 to 50 amps. on average charge, and maximum discharge of 200 amps. with a machine variation of about 25 amps. maximum. The battery is located in a power house about a mile and a half from the generating station.

Battery Installation and Attendance.

The acid when put into the cells should have a specific gravity of 1180 degs. to 1190 degs.

The charge should then at once be commenced at about half the normal rate. After charging at this rate for a short time and it is determined that all connections are well made, the rate should be raised to the normal and continuted for about 20 consecutive hours or until the potential of each cell reaches 2.5 volts and all the cells are gassing freely from both positive and negative plates. The specific gravity of the electrolyte which fell shortly after the cells were filled, should now have reached at least 1200 degs. At this point the charging rate should be reduced to one-half the normal and continued until the electromotive force of each cell has again reached 2.5 volts.

The regular service of the battery may now be commenced. On the subsequent charges to the number of five, the cells should be brought up to 2.6 volts per cell at the normal rate or preferably 2.5 at half that.

When the battery is in use as a regulator enough generator capacity must be carried to meet a little more than the average demand of the load, and the bus voltage must be kept up to the average. That is, the battery must charge a little more than it discharges.

The battery will regulate best when about 75 per cent full. The individual cell voltage will then be about 2.08 volts. The specific gravity should be between 1190 degs. and 1200 degs.

In its work as a regulator the battery should not discharge at a higher rate than specified by the manufacturers, nor should any individual cell at any time read lower than 1.8 volts when discharging at the normal rate. The battery must never stand discharged, but must be thoroughly charged on reaching the above point.

A full charge should be given the battery once a week, when all the cells should be individually tested with low reading voltmeter and hydrometer. No cell at the end of this charge should read less than 2.5 volts when charging at the normal rate. At the end of this charge the specific gravity should not be below 1200 degs.

Pure water, distilled if necessary, must be added to make up for electrolyte lost by evaporation. This water should not be added in large enough quantities to reduce the specific gravity to any considerable extent. It should be added at the bottom of the cell through a rubber hose or glass tube to insure its thoroughly mixing with the electrolyte. The plates should always be covered by the electrolyte.

The positive plates should have a dark brown velvety appearance. Any lightness in color indicates insufficient charging. No attention need be paid to a whitish precipitate that sometimes appears on the plates. The negatives should have a clear bluish lead or light slate color.

If there occurs a time during which it is not convenient or possible to carry on the generators the entire average load on the plant the discharges of the battery may be allowed to exceed the charges up to the capacity of the battery.

About the only form of trouble that is likely to occur in a cell is a short circuit complete or partial between the positive and negative plates. This will be indicated by low voltage and low specific gravity and should be at once removed. Its most probable cause is the lodging between the plates of some foreign article or a loosened part of the plates themselves. It may also be due to the depth of the sediment in the bottom of the cells reaching the bottom of the plates. If the short circuit is due to a foreign body, it should be removed; if to a loosened portion of the plates, it may be forced to the bottom of the cell; if to sediment, the cell should be cleaned out.

When Chloride Accumulators are in use, it will be found that there is a constant slight loss of solution. This is principally due to the evaporation of the water from the mixture of water and sulphuric acid, of which the solution is composed. Use pure water to replace that lost by evaporation. The water should be absolutely free from chlorine (common salt), and contain not more than a trace of iron and other metals. Always use distilled water when it can be obtained; fresh rain water is also suitable. The solution should always entirely cover the plates in every cell. The proper density for the solution in a charged cell is 1200 degs. The specific gravity of the solution should be tested with a hydrometer at least once a week. The test should be made just after the cell has been fully charged. A decrease in the density of the solution in a fully charged cell is not due to evaporation, as the acid does not evaporate. Some of the acid in the solution may be lost, however, by the spraying which occurs during the latter part of the charge. By the violent evolution of gases at that time small particles of dilute acid are thrown upward and prevented by air currents in the room from falling back into the cells. As this is replaced by water in the regular filling up of the cells, the specific gravity may be lowered from this cause. For this reason, it is not safe to always replace evaporation only with clear water on the assumption that no acid has been lost.

Loss of water tends to increase the strength of the solution. When hydrometer readings, taken at the end of charge, indicate that the density of the solution is low, a mixture of pure sulphuric acid and water of a specific gravity of 1400 degs. (one part sulphuric acid and one part water, by volume—not by weight) should be prepared and when cool, a sufficient quantity of the dilute acid should be thoroughly mixed with the solution in the jar to raise the specific gravity to 1200 degs. as shown by hydrometer readings.

The density of the solution will vary with the condition of the cell, the density in a discharged cell being lower than in a charged cell. During the discharge, the acid is drawn from the solution into the plates; and during charge, this acid is again released. A low density of the solution, when the cell is apparently charged, does not, therefore, necessarily mean a lack of acid, as the low density may be caused by insufficient charging, that is, the acid may be in the plates instead of in the solution.

Before adding the mixture of acid and water to the solution in the jar, it should be known that the cell is fully charged. A cell may be considered fully charged when with the normal charging current flowing, voltmeter readings show the cell to have an e. m. f. of 2.5 volts. If the cell be charged at three-quarters of the normal charging rate, the charge should be continued until the cell shows an e. m. f. of 2.45 volts; if the cell be charged at one-half the normal

THE CHLORIDE ACCUMULATOR.—TYPE "G."

SIZES OF PLATES, 15½ INS. x 15½ INS.

Number of Plates		15	21	27	35	41	49	61	71	93	105	125
Discharge in Amperes	For 8 hours	140	200	260	340	400	480	600	700	920	1040	1240
	5 "	196	280	364	476	560	672	840	980	1288	1456	1736
	3 "	280	400	520	680	800	960	1200	1400	1840	2080	2480
Normal charge rate		140	200	260	340	400	480	600	700	920	1040	1240
Weight of each element, lbs.		300	422	544	707	829	991	1235	1439	1886	2131	2538
Outside Measurment of Tank in inches,	Width	18⅜	23⅜	29⅜	36	40⅞	47½	58¼	66½	84¾	94⅝	111¼
	Length	19¾	19¾	20¾	20¾	20¾	20¾	21½	21½	21½	21½	21½
	Height	22⅞	22⅞	23⅜	23⅜	23⅜	23⅜	24¾	24¾	24¾	24¾	24¾
Weight of acid, lbs		197	255	312	388	444	520	635	729	938	1051	1242
Weight of cell complete, with acid in lead-lined tank, lbs.		621	829	1066	1351	1563	1848	2277	2633	3418	3845	4560
Height of cell over all, inches		26	26	28	28	28	28	29	29	29	29	29

THE GOULD STORAGE BATTERY.—TYPE "S."

DIMENSIONS OF PLATE, 15½ INS. x 15½ INS.

Element Number		605	607	609	611	613	615	617	619
Number of Plates		5	7	9	11	13	15	17	19
Normal Charging Rate		40	60	80	100	120	140	160	180
Discharge in Amperes,	For 8 hours	40	60	80	100	120	140	160	180
	" 5 "	56	84	112	140	168	196	224	252
	" 3 "	80	120	160	200	240	280	320	360
Capacity in Ampere, Hours.	At 8 hrs. discharge	320	480	640	800	960	1120	1280	1440
	" 5 hrs. discharge	280	420	560	700	840	980	1120	1310
	" 3 hrs. discharge	240	360	480	600	720	840	960	1080
Weight of element, lbs.		160	180	200	220	260	300	340	380
Outside dimensions of heavily glazed earthen tank in ins.	Width	11	12½	13½	15½	17	18½	20	22
	Length	21	21	21	21	21	21	21	21
	Height	24	24	24	24	24	24	24	24
Outside dimensions of lead-lined tank in inches	Width	11	12½	13¾	15	17	18½	20	22
	Length	20	20	20	20	20	20	20	20
	Height	23	23	23	23	23	23	23	23
Height of cell over all in ins.		26	26	26	26	26	26	26	26
Weight of acid in tank, lbs.		100	120	140	160	180	197	216	235
Weight of cell, complete, lbs.		275	345	415	485	555	625	692	768

rate, the cell should have an e. m. f. of 2.4 volts, and if the charge be at one-quarter of the normal rate, the cell should have an e, m. f. of 2.35 volts. If a voltmeter is not available, a cell, generally speaking, may be considered fully charged, when both the positive and negative plates have been gassing freely for fifteen minutes.

To prepare dilute sulphuric acid, always pour the acid into the water, never the water into the acid. It is advisable to prepare the solution at least twelve hours before using, in order that it may thoroughly cool. Solution of specific gravity of 1200 degs. is composed of one part sulphuric acid having a density of 66 degs. Beaumé, and three parts of water.

THE BOOSTER.

The function of the booster in a railway plant is to assist the long feeders to maintain their potential at the ends of the line. Usually a series wound booster is used, whose function is to increase the line potential as the current flow through the booster increases. The rise in potential in the booster can be made equivalent to the drop in potential on the feeder. This may be obtained from a booster either by having its series winding compensate for the line drop or by shunting part of the series turns by a shunt winding whose magnetic effect can be opposed to or in the same direction as the series winding. It is usually the custom to group the distant feeders together on one booster. This booster may be operated by a motor or by an engine, but it is preferable to use the latter.

In a number of stations there will be found the older type generators, kept for reserve capacity, and these can be changed into boosters by making the connections shown in Fig. 334. The machines can still be used as generators when required.

The feeders to be boosted are grouped together on a bus-bar, which is connected to the main bus bar by switch, *A*. Feeding this bus is a generator having a double-throw double-pole switch. When switch *A* is open and switches *B*, *B*, from the generator are thrown in the lower position, the current then passes through generator *F* from the bus to the boosted feeders in a direction to increase the potential of this current.

When the switches on generator *F* are thrown in the position *C C*, the generator is used simply as a generator and *A* can be closed, and the feeders will not be boosted. This condition is especially useful for parks and special outlying

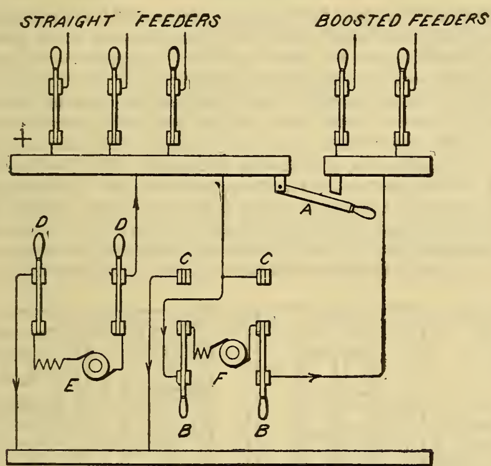


FIG. 334.—DIAGRAM OF CONNECTIONS FOR CHANGING GENERATOR TO BOOSTER.

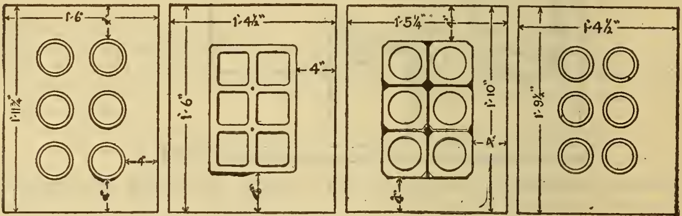
attractions, where the traffic is large for a short time; and it saves the investment for a booster. The capacity of generator *F* should be equal to the maximum demand on the feeders, or a number of generators can be supplied with double-throw switches and connected as shown for the single generator, and used as multiple boosters.

The shunt field can be excited or not if the copper is light for the maximum demand, and in this way cars can be moved more economically for short periods than by the investment in copper or boosters, and gives a double use for the same generator. The amount of boosting will depend upon the series turns on the generator, but if too much, it can be shunted and if too little, can be increased by the shunt winding on the generator.

Appendix II.—Underground Conduits.

CABLE CONDUITS.

Where railway feeders have to be carried underground it is necessary to lay a multiple duct with man-holes along the streets through which the railway passes. The material used for these ducts was originally wood, which was treated with dead coal tar and asphalt compounds to make it impervious to moisture. One method was to use grooved planking, two halves of which formed the duct, and a number of these were built up together to form a rectangular ductway with holes from 3 ins. to 3½ ins. in diameter. This ductway was made impervious by the application of asphaltum compound. The other method was the pump log construction, where a rectangular beam 4 ins. to 5 ins. square was used, through the center of which a 3 to 3½ in. hole was bored. These logs were provided with a turned end which projected into a recess turned into the adjacent section for alignment and were driven together, nailed and served with a moisture resisting compound, and sometimes laid on, as well as covered with, concrete.



FIGS. 335, 336, 337, 338.—FORMS OF CONDUIT.

A cement duct was also largely used for this purpose, and was made by covering a thin sheet iron pipe with cement to a depth of about ½ in. These were laid together, the ends being provided with cast-iron nozzles. The cement conduits were laid up in concrete forming a solid mass. A section of these cement ducts as laid is shown in Fig. 335. Fig. 338 shows a wrought-iron pipe laid in cement and concrete. This form of duct has great flexibility and is often used where a number of obstructions are to be avoided.

The Camp terra cotta duct is shown in Fig. 337. It is made of sections of vitrified terra cotta laid together in cement mortar and surrounded with concrete, the joints being staggered so as to increase the strength of the whole structure.

McRoy ducts, Fig. 336, are molded in one piece, the alignment being obtained by the use of dowel pins inserted in the holes of abutting surfaces of the ducts. These ducts vary from 3 ft. 6 ins. to 18 ins. from the top of the cement over the conduit to the street surface depending upon the frost conditions and other obstructions and the facility for drainage.

Foundations, Etc.—The foundations on which any conduit system is laid should be at least 3 ins. to 6 ins. of concrete well tamped down on firm ground, on which flat surface should be laid the duct, and on each side of them tamped concrete in order to make the duct structure a continuous whole. Old conduit work shows the importance of a good foundation, as it will crack and fall out of alignment unless great care is taken in providing with a proper bed. The mortar used in concrete bedding and filling is generally 1 part cement to 3 parts clean sharp sand. It is generally included in specifications that all trenches shall be sheeted and braced, and such bridges and crossings as may be required shall be kept in place, so as to interfere with traffic as little as possible. In refilling trenches only the best part of the material excavated should be used; this must be thoroughly tamped and rammed, rolled or flushed as may seem necessary in order that the pavement on top of the conduit does not settle after completion.

It is the general practice so to lay the ducts as to make the conduit as nearly square as possible, and the alignment of the ducts is tested by drawing a $2\frac{15}{16}$ in. mandrel at least 18 ins. long from man-hole to man-hole. This test is generally required before the acceptance of the work. The layers of ducts should be separated with concrete in order to obtain a diameter of 5 ins. between centers of any two ducts, but this varies with the character of conductor to be drawn in. It is also required of the contractor to leave iron wires extending from man-hole to man-hole in each duct sufficiently long to be turned down to prevent slipping back into the duct.

Terra cotta or earthenware pipes should be impervious to moisture, and can be tested by being plugged at one end and filled with water, or the conduit can be broken and tested for vitrification by the method given for porcelain on pages 75 and 76.

Man-Holes vary in number from 20 to 25 per mile, and are regulated by the size of the cables, the size of the ducts, and the strains to which the cable can be submitted for drawing through. The glazed ducts allow of drawing longer distances with less tension on the cable than the wooden or iron ducts. The construction of a standard form of man-hole is shown in Fig. 339. These are laid in hard burnt sewer brick in mortor cement, and the brick should be thoroughly wet before being laid. Where the man-hole is subjected to surface moisture or placed in soft ground it is usual to grout heavily on the outside of the brickwork to prevent the seepage of moisture through the walls. The ducts entering the man-holes can be staggered and in some cases bricks are left projecting into the man-hole for the purpose of sustaining the cables in passing around a man-hole. The floor should be laid at least 1 in. deep in cement, 1 part sand to 1 part cement, in order to avoid moisture creeping into the mau-hole. The man-hole has a bed from 6 ins. to 8 ins. deep of concrete, made of 1 part cement to 3 parts sand and 5 parts broken stone passing through a $1\frac{1}{2}$-in. ring. The iron work can be ordinary I-beams laid as shown in the cut, and the dimensions of the man-hole can be varied according to the number of cables entering. Where the ducts slope toward the man-hole it should be trapped to the sewer, the trap being introduced underneath. In this case the floor should be sloped slightly so that drainage runs into the sewer. Gases accumulate in city streets in these man-holes and ductways where not filled with wire, and explosions have occured from this cause. To avoid accidents of this kind several methods have been used, the simplest one being to run standpipes up from the man-hole to the curb; and in some cases the tubular iron poles for the span wires have been used for ventilating the ducts, being provided on top with a ventilating cap.

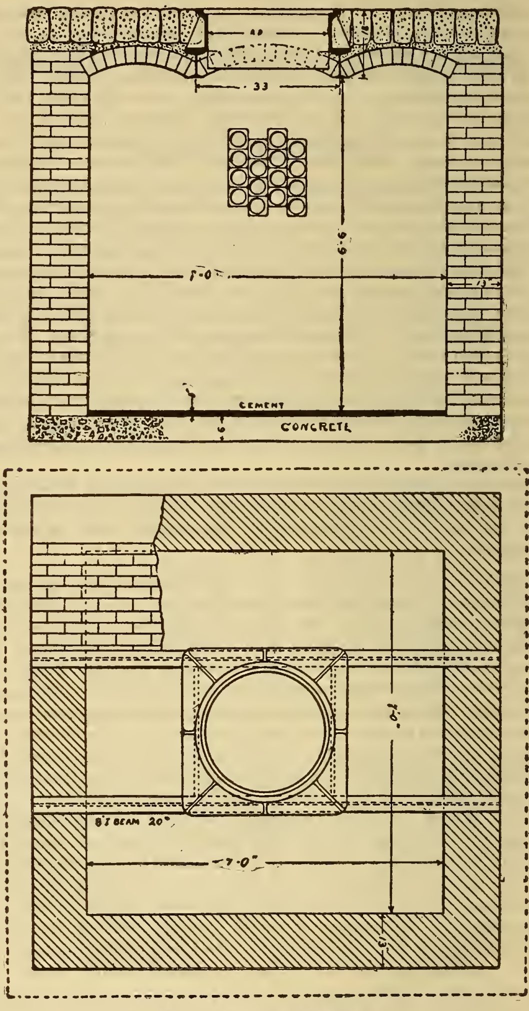


FIG. 339.—MAN-HOLE CONSTRUCTION.

Where the feeding to the trolley wire is between man-holes the top duct is selected and connection made from the cable through tap wire in a pipe curved to a 3-ft. radius which enters the bottom of the iron trolley pole or is secured to the outside of a wooden one. It is less expensive, if possible, to tap from the man-hole and here the drawing in and out of the tap can be readily accomplished without opening the street to connect the cable to the span wire. Fig. 340 shows the method largely in vogue for this purpose, the one shown being that used by the Union Traction Company, of Philadelphia. Here the cable is ended in a conical brass terminal which enters the lug connected to the feeding wire.

Where gas has accumulated in the duct special ventilating methods of forced air are employed to either clear the man-holes of gas or maintain the pressure at about 6 oz., so as to prevent the introduction of gas into the man-holes and ducts.

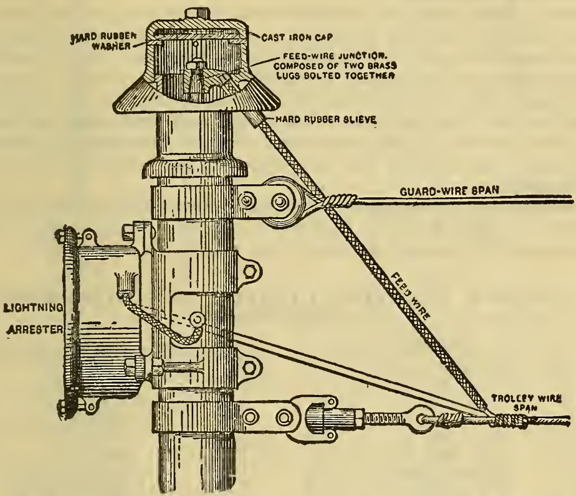


FIG. 340.—METHOD OF CONNECTING UNDERGROUND CABLE TO OVERHEAD LINE CONSTRUCTION.

Blower methods have been used by which the man-holes have been exhausted of the gas accumulating. The special points to be guarded are the top of the man-holes where the cover rests on the concrete and where the ducts enter the man-hole. Backing carefully with concrete or mortar leads to better air in the man-holes.

The Conductors.—The cables used for railway work are made of stranded wire, so the cable can be bent to a radius of 3 ft. with no fracture of the lead covering. Where rough or imperfect ducts are to be drawn through, the cable is sometimes covered with a braiding of jute, and where the tension required is great the cable is slicked with tallow.

The usual method of pulling in rope for drawing the cable is by rodding which consists of using a number of rods having screw connections, each long enough to go into the man-hole and enter the duct. The first rod is passed in and screwed to the next and so on until a continuous rod has been shoved through to the other end. The rope is attached to the last rod and the rods are then taken out at the distant man-hole drawing the rope through the duct.

The thickness of the insulation is stated in 64ths of an inch and should be such a material as to be capable at all times to stand a current density on the conductor of not less than 1 amp. for 1000 circ. mils, and at a pressure at least twice that specified as the working pressure of the cable. Where paper is used as the di-electric or insulator it should be pure manila fibre spirally wound in overlapping strips and treated with such compounds as shall not in any way deteriorate its insulating qualities. If the insulator is rubber all the conductors should be thoroughly tinned and the rubber compound contain not less than 35 per cent pure para rubber.

The sheathing should be composed of pure desilverized lead with such alloy of tin as may be considered proper, and should be of sufficient thickness to withstand mechanical injury. It is usual to allow 3 per cent tin to improve the lead's resisting qualities against the gas and moisture to which it is submitted in the ducts. The conductor should be of soft-drawn copper with a conductivity of not less than 98 per cent that of pure copper; each strand shall be such that the sum of the areas of their cross-sections when all strands are laid out straight and cut at right angles to their axis is equal to the total circular mils of the cables specified.

The following table gives the approximate current densities usually allowed in subways. The insulation resistance in megohms per mile ranges between 200 megohms and 250 megohms for a voltage ranging from 300 to 1000.

MAXIMUM CARRYING CAPACITY OF UNDERGROUND CONDUCTORS.

SIZE OF CONDUCTOR.	MAX. SAFE CARRYING CAPACITY.
B. & S. Gage.	Amperes.
1	129
0	151
00	175
000	213
0000	247
Circular Mils.	
250,000	280
300,000	320
350,000	357
400.000	394
450,000	429
500,000	463
550,000	497
600,000	530
650,000	562
700,000	593
750,000	624
800,000	654
850,000	683
900.000	712
950,000	741
1,000,000	769

CONDUIT ROADS.

The construction for a subsurface trolley road presents the following engineering problems: the insulating of two conductors within 6 ins. of each other, the insulation to be subjected to moisture, and the proper drainage of the conduit. The Metropolitan Street Railway system in New York may be taken as standard and a description of its construction follows: The yokes are each 425 lbs. in weight,

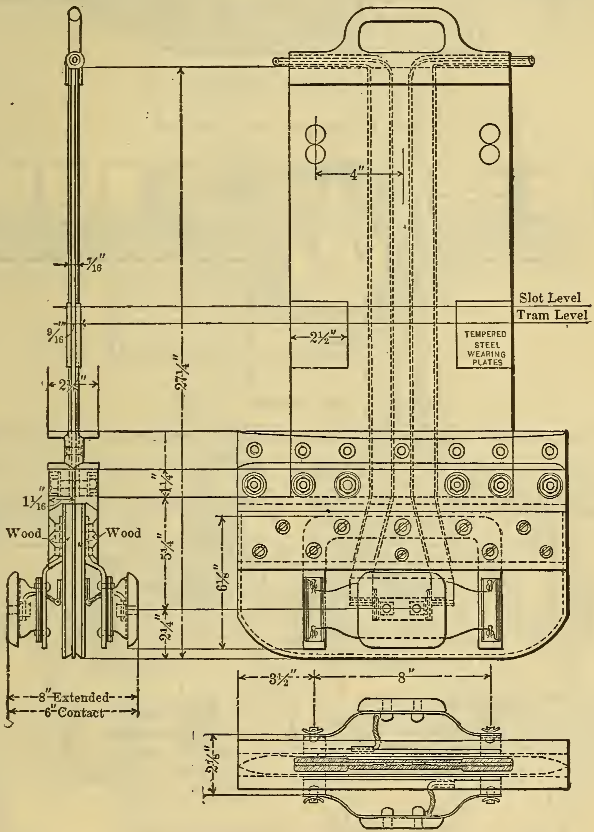


FIG. 341.—CONSTRUCTION OF PLOW FOR UNDERGROUND CONDUIT.

and are illustrated in Fig. 342, which shows the complete cross-section of a double track road. The yokes are spaced 5 ft. apart. The excavation is made through the street, 18 ft. 9 ins. wide and 30½ ins. deep for the conduit and 15 ins.

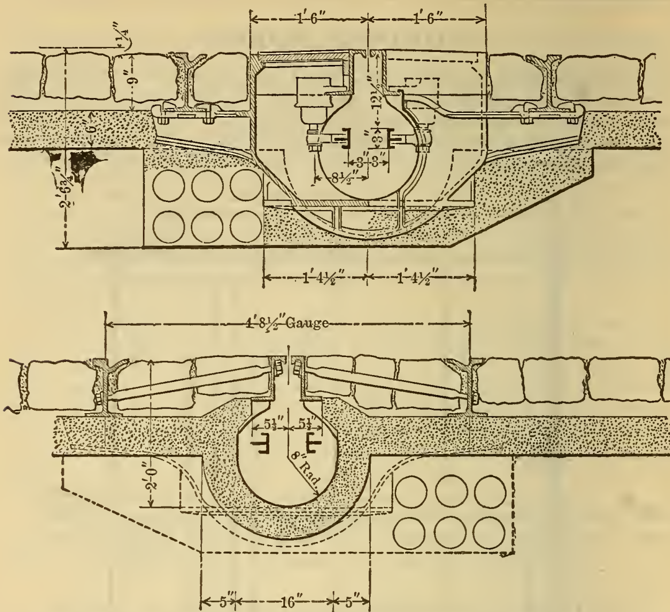


FIG. 342.—CROSS SECTIONS OF UNDERGROUND CONDUIT CONSTRUCTION, NEW YORK.

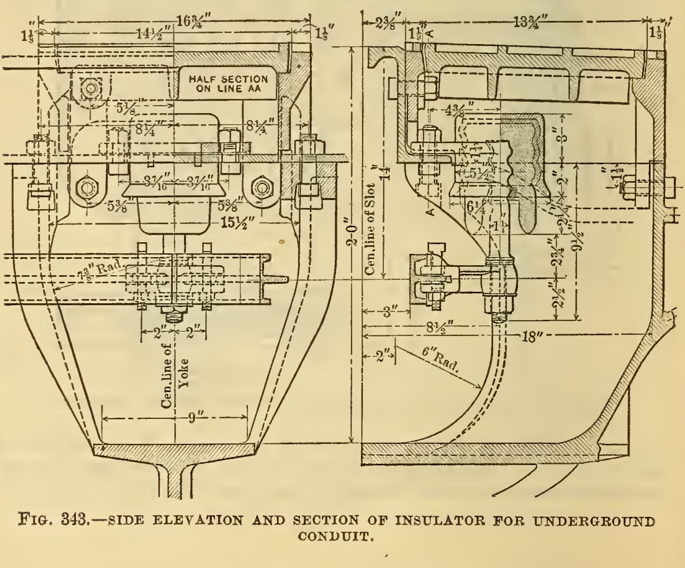


FIG. 343.—SIDE ELEVATION AND SECTION OF INSULATOR FOR UNDERGROUND CONDUIT.

between tracks. The track and slot rails of the conduit are then laid on the yokes, and tie rods then inserted and the whole structure blocked up surfaced and lined. The concrete is made of 7 parts ¾-in. broken stone, 4 parts sand and 1 part Portland cement, and placed under and around the conduit opening. An iron hand-hole cover is located above each insulator, which are 15 ft. apart. The man-holes average about 150 ft. apart and there entrance is generally between the tracks. At these points the conduits drain into the sewers.

The bottom of the conduit is pitched at a minimum of 2 ins. to the 100 ft. in case of a level track to give drainage. Fig. 343 shows the construction of an

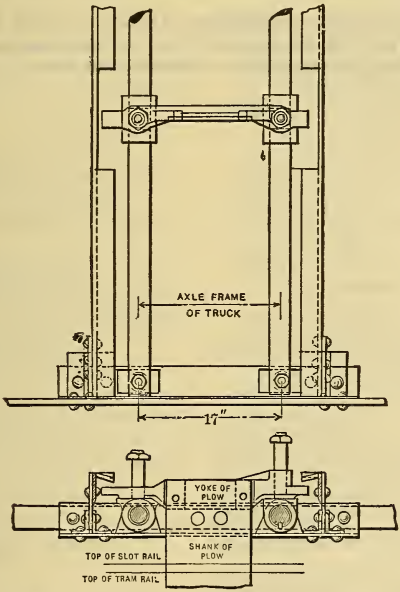


FIG. 344.—METHOD OF ATTACHING PLOW TO CAR.

insulator and the method of fastening the T-iron conductor to it, against which the contact shoe rubs and from which the current is collected for the operation of the car. Fig. 341 shows the method of construction of the contact shoe or plow and Fig. 344 shows how it is supported by two angle irons underneath the truck.

THIRD-RAIL SYSTEMS.

For third-rail work the ordinary section of rail is usually used. The Manhattan Elevated Railway Company has used soft iron rail to improve the conductivity. The insulation of the third-rail, where it is the positive side of the circuit, has been found by Boynton to be such that when insulated on blocks 1½ ins. thick attached to ties not creosoted but dipped in insulating compound, no leakage was noticeable. In another test on one-half mile of track one-half ampere leakage occurred when dry and one and one-quarter ampere when wet.

It was found both in conduit rails and exposed rails that the positive rail retains its insulation when current leaks over the surfaces, whereas it is much harder to hold the insulation with the negative rail on acccount of the tendency of moisture to increase the negative leakage.

On the third-rail the current is collected by a shoe on a projecting arm beyond the car sliding over the rail and flexibly connected to the arm by two laced joints, but the electrical connection is made directly from the shoe to the car wiring circuit.

Both the third rail and the underground conduit rail have been successfully operated when under water, especially where the water was pure. Slush is the most difficult thing to contend with in exposed conductors.

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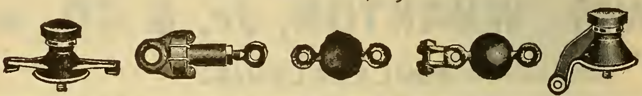

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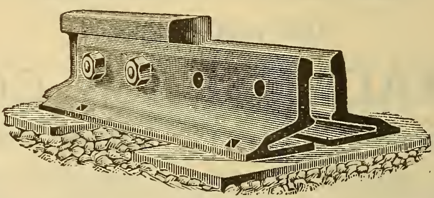

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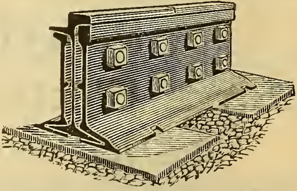

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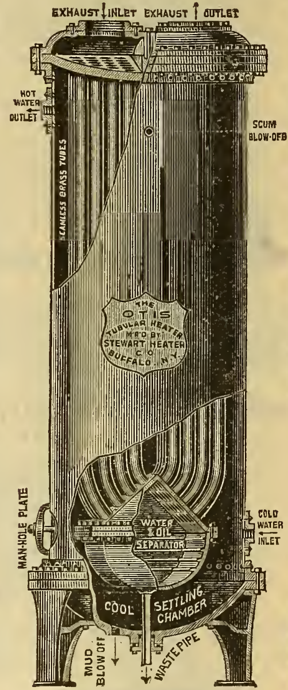

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MECHANICAL STOKERS.

Mechanical stokers are divided according to their method of operation into two classes—the OVERFEED and the UNDERFEED. The Overfeed type is simply a modification or an improvement upon the common flat grate method of firing, this type including movable grate bars, either rotary or oscillating, as well as the traveling grate. Being dependent entirely upon natural draft, stokers of this kind are therefore subject to the same criticisms which apply to ordinary hand-fired practice. One of the chief faults is, that the greatest amount of air is supplied where the fire is thinnest, while the least air reaches the heaviest part of the fire bed, this being exactly contrary to the theory of combustion. Furthermore, it is impossible with this kind of mechanical firing to use with economy the cheaper grades of fuel, as a large percentage of this cheap fuel passes unconsumed into the ash pit. To these disadvantages named above can be added a third, namely, the extreme cost of repairs. The working parts of these stokers are of necessity subjected to the full heat of the furnace and being only protected by the natural draft, burn out rapidly, especially where fuel inclined to clinker is used. The Underfeed type of stoker, of which the American Stoker is the only practical exponent, feeds the coal from beneath the fire. The coal rising slowly toward the surface of the fire becomes heated and so releases all the combustible gases, these gases of necessity passing through the incandescent coal bed above before reaching the stack. At the point of ignition, a supply of air is introduced under a light pressure, the amount of oxygen being equal to that demanded theoretically for perfect combustion. This air reaches the fire at its heaviest part, just where the most oxygen is needed. It will be seen, therefore, that the American Stoker follows closely the theoretical demands for perfect combustion and in addition avoids one of the greatest weaknesses of the Overfeed type, as none of the working parts of the stoker are subjected to the action of fire. Another great advantage lies in the ability to use the cheapest grades of coals and without loss of fuel in the ash pit. As all combustible gases must pass through the incandescent fire bed before reaching the stack, the hydro-carbons are consumed and consequently the problem of smoke prevention is solved. The American Stoker is now considered the standard automatic stoker both in the United States and Europe and is fully protected by patents in all countries.

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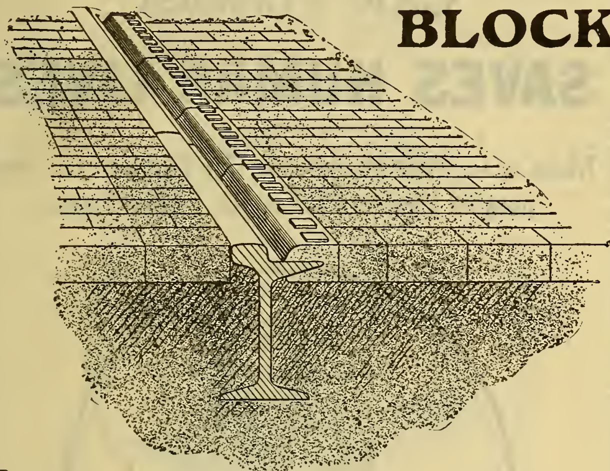

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